Life Science

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Chapter 1

Studying Life

1.1 Lesson 1.1: The Nature of Science

Lesson Objectives

- Understand that science is a system based on evidence, testing, and reasoning.
- Describe what the life sciences are and some of the many life science specialties.
- Describe the scientific method and why it is important.
- Define the words "fact," "theory," and "hypothesis."
- Describe some of the tools of life science.
- Know that scientists are required to follow strict guidelines.

Check Your Understanding

- What do you expect to learn from this class?

Introduction

Before proceeding through this class, you need to realize a number of fundamental concepts of science. You need to:

- Know that science is a way of knowing about the physical world, based on observable evidence, testing predictions, and reasoning
- Understand that, in science, theories and knowledge are constantly tested and questioned.
- Know that, when new information conflicts with existing explanations, scientists modify their explanations to be consistent with all evidence.

- Understand that principles of philosophy and religion usually cannot be tested scientifically, because they are not based on observable evidence.
- Identify what the life sciences are and some of the many specialties
- Know the difference between scientific theory and fact.

These raise several interesting questions:

1. Why is modern science producing many more improvements in our lives than it did a hundred years ago? Modern science is based on evidence, inquiry and testing which have replaced personal beliefs, mythology and other biased sources of information.
2. Is there anything that science cannot explain? Yes there is. Questions about ethics (right and wrong) and belief in supernatural forces can not be explained through science.
3. How can we "think like scientists?" To think like a scientist, you would need to:
   (a) ask questions about the world around you and seek new evidence that will help answer questions,
   (b) base your understanding of the world on evidence, testing and reasoning instead of biased belief systems,
   (c) continuously question and test the accuracy of your knowledge and assumptions (including so-called "common sense").

Goals of Science

Science, religion, mythology, and magic share the goal of knowing about and explaining the world, such as the physical world, but their approaches are vastly different. The difference between them is their approach to "knowing." The vastness of the living, physical world includes all organisms (**Figure** 1.1), on land (**Figure** 1.2) and in the sea (**Figure** 1.3). As humans, some of the things we want to know and understand are what makes us healthy, what makes us sick, and how we can protect ourselves from floods, famine and drought.

Throughout history, humans have looked for ways to understand and explain the physical world. Try to imagine what humans thought about themselves and the world around them 1,000 years ago, or 5,000 years ago, or more. If you were born then, how would you have explained why the sun moved across the sky, then disappeared? How would you explain why your body changes as you grow, or birth and death? What explanation would you have for lightning, thunder, and storms?

Throughout time, different cultures have created hundreds of different myths and stories and even gods to explain what they saw. Ancient Greeks explained that lightning was a show of their god Zeus' anger. Scandinavians claimed that their god of thunder, Thor, was responsible for the rumbling and bolts of lightning. Without any formal science, many cultures have also blamed diseases, such as epilepsy, on evil spirits and other imaginary

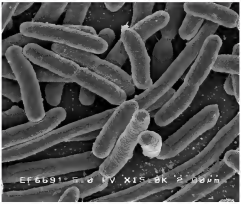

Figure 1.1: *Escherichia coli* bacteria (25)

Figure 1.2: A male lion. (9)

Figure 1.3: A Humpback whale. (15)

entities. For example, there is evidence that many different cultures drilled holes in the skulls of patients who had seizures or other maladies, thinking that they were releasing evil spirits.

Science as a Way of Knowing

During your own and your parents' lifetimes, advances in medicine (**Figure** 1.4), technology, and other fields have progressed faster than any other time in history. This explosion of advances in our lives is largely due to human use of modern science as a way of understanding. Today's scientists are trained to base their comprehension of the world on evidence and reasoning rather than belief and assumptions.

Figure 1.4: The anatomy lesson of Dr. Nicolaes Tulp. (26)

Modern science is:

- A way of understanding about the physical world, based on observable evidence, reasoning, and repeated testing.
- A body of knowledge that is based on observable evidence, experimentation, reasoning, and repeated testing.

As we learn more, new information occasionally conflicts with our current understanding. When this happens scientific explanations are revised. The **Figure** 1.5 demonstrates this. However, science cannot scrutinize what is good versus what is bad (morality), because these are values, ideas that lack measurable evidence. Science is not used to examine philosophy

Figure 1.5: In 1847, a doctor, Ignaz Semmelweis, demonstrated that when he washed his hands before delivering babies fewer women died from infection. Before this, doctors held untested beliefs about the causes of disease, such as a person's behavior, or the air they breathed. (5)

or supernatural entities, such as the existence or nonexistence of a god. However, science can be used to examine the effects of these experiences.

The most important message from this chapter is that science is not only a way of knowing it is also a way of thinking and reasoning. Scientists try to look at the world objectively - without bias or making assumptions. How? Scientists learn to be skeptical, to question the accuracy of our ideas. They learn to base their understanding of the physical world on evidence, reasoning and repeated testing of ideas.

To Think Like a Scientist

To think like a scientist, you need to be skeptical about and question your assumptions, including what often seems like common sense. Questioning ideas can often lead to surprising results. For example, if you ask people whether it's easier to keep a plastic cutting board clean or a wooden one clean, most people will think that the plastic board is easier to keep clean and has fewer germs (**Figure** 1.6).

Why do most people believe that plastic is safer? Probably because we assume that it is easier to wash germs off plastic than off wood. This assumption is promoted by the makers of plastic cutting boards and it sounds reasonable. After all, wood stains and looks unhygienic; plastic cutting boards come out of the dishwasher shiny and clean looking. But is plastic

Figure 1.6: Which is safer, a plastic or wood cutting board? (3)

actually better?

When scientists tested this idea, the answer turned out to be no. The researchers treated used cutting boards with different kinds of germs and then washed the boards. They found, much to their surprise, that gouged and sliced wooden cutting boards had far fewer germs than gouged and sliced plastic boards. The researchers discovered that germs that cause food poisoning, such as *E. coli* and *Salmonella*, are absorbed into the wood and seemed to vanish. On plastic, the germs sit on the surface in cuts in the plastic where they are difficult to clean out but can contaminate food. Furthermore, in a different study of food poisoning, people who used wooden cutting boards were less than half as likely to get sick as people using plastic ones.

"Common sense" may seem to have all the answers, but science is all about following the evidence. So what is good evidence? Evidence is information that can be used to confirm or refute an idea or to explain something. Both scientists and lawyers use evidence to support an idea or to show that an idea is probably wrong. Scientific evidence has certain features, which may be different from legal evidence.

Evidence is:

1. a direct, physical observation of a thing, a group of things, or of a process over time.
2. usually something measurable or "quantifiable."
3. the result of something.

For example, a book falling to the ground is evidence in support of the theory of gravity. A bear skeleton in the woods would be supporting evidence for the presence of bears.

What Are the Life Sciences?

The life sciences are the study of living organisms and how they interact with each other and their environment. These include all the biological sciences. Life sciences deal with every aspect of living organisms. The life sciences are so complex that most scientists focus on just one or two subspecialties — see tables 1.1, 1.2, and 1.3. Also, some focus on the relationship between living organisms, which is depicted in a phylogenetic "Tree of Life" (**Figure** 1.7).

Table 1.1: **Subspecialties that focus on one type of organism**

Subspecialty	Studies	Subspecialty	Studies
Botany	plants	**Zoology**	animals
Marine biology	organisms living in and around oceans, and seas	**Fresh water biology**	organisms living in and around freshwater lakes, streams, rivers, ponds, etc.
Microbiology	microorganisms	**Bacteriology**	bacteria
Virology	viruses	**Entomology**	insects
Taxonomy	the classification of organisms		

Table 1.2: **Fields of life sciences that examine the structure, function, growth, development and/or evolution of living things**

Life Science	What it Examines	Life Science	What it Examines
Cell biology	cells and their structures	**Anatomy**	the structures of animals
Morphology	the form and structure of living organisms	**Physiology**	the physical and chemical functions of tissues and organs
Immunology	the mechanisms inside organisms that protect them from disease and infection	**Neuroscience**	the nervous system
Developmental biology and embryology	the growth and development of plants and animals	**Genetics**	the genetic make up of all living organisms (heredity)
Biochemistry	the chemistry of living organisms	**Molecular biology**	biology at the molecular level
Epidemiology	how diseases arise and spread (**Figure** 26.3)		

Table 1.2: (continued)

Life Science	What it Examines	Life Science	What it Examines

Table 1.3: **Fields of biology that examine the distribution and interactions between organisms and their environments**

Life Science	What it Examines	Life Science	What it Examines
Ecology	how various organisms interact with their environments	**Biogeography**	the distribution of living organisms (**Figure** 1.9)
Population biology	the biodiversity, evolution, and environmental biology of populations of organisms		

Scientific Theories

Science theories are produced through repeated studies, usually performed and confirmed by many individuals. Scientific theories are well established and tested explanations of observations. These theories produce a body of knowledge about the physical world that is collected and tested through the scientific method (discussed in the Scientific Method lesson).

The word "theory" has a very different meaning in daily life than it does in science. When someone at school says, "I have a theory," they sometimes just mean a hunch or a guess. This everyday meaning for "theory" can confuse people when well-tested and widely accepted scientific theories are discussed by nonscientists. For example, the theory of evolution is a well-established scientific theory that some people incorrectly say is just a hunch.

A scientific theory is based on evidence and testing that supports the explanation. Scientific theories are so well studied and tested that it is extremely unlikely that new data will discredit them. The idea that matter is made up of atoms, evolution, and gravity are all scientific theories about how the world works that scientists accept as fundamental principles of basic science. However, any theory may be altered or revised to make it consistent with new evidence.

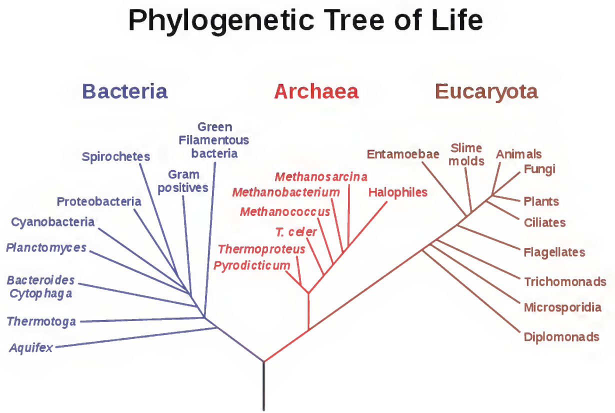

Figure 1.7: **The Phylogenetic Tree of Life** shows the relationship between living organisms. Humans and other mammals (eukaryotes) appear on the right side of the tree. The base of the tree represents the ancestor of all living organisms. (8)

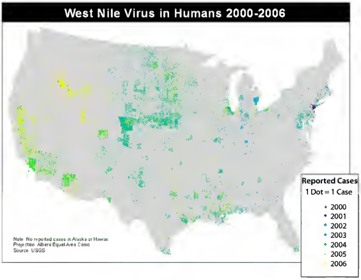

Figure 1.8: Epidemiologists study how diseases spread. The above map shows where humans contracted West Nile Virus between 2000 and 2006. It is believed the virus entered the United States in New York City in 1999. Notice how rapidly the virus spread across the U.S. (13)

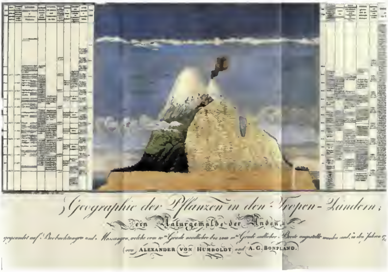

Figure 1.9: Alexander von Humboldt mapped the distribution of plants across landscapes and recorded a variety of physical conditions such as pressure and temperature. Today, biogeographers study the diversity and distribution of organisms across Earth. (20)

Two Important Life Science Theories

In the many life sciences, there are possibly hundreds or thousands of theories. Yet there are at least two fundamental theories, which provide a foundation for modern biology. They are:

1. The Cell Theory
2. The Theory of Evolution

The Cell Theory

The Cell Theory states that:

- All organisms are composed of cells (**Figure** 1.10).

- Cells are the basic units of structure and function in an organism.
- Cells only come from preexisting cells; life comes from life.

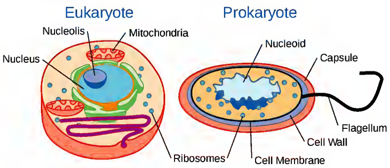

Figure 1.10: The two types of cells, eukaryotic (left) and prokaryotic (right). (10)

The development of the microscope in the mid 1600s made it possible to come up with this theory (**Figure** 1.11).

The Theory of Evolution

In biology, evolution is the process of change in the inherited traits of a population of organisms over time. Natural selection is the process where organisms that are better suited to the environment are more likely to survive and reproduce than others that are less suited to the environment. This theory basically states that better suited organisms live longer and have an easier time reproducing, passing on their traits that made them better suited

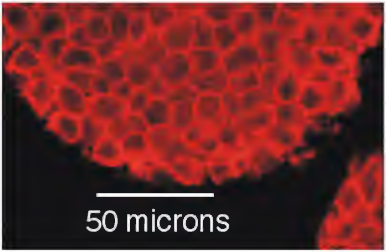

Figure 1.11: A mouse cell viewed through a microscope. (7)

to their environment. The theory of evolution by natural selection is often called the "great unifier" of biology, because it applies to every field of biology. It also explains the tremendous diversity and distribution of organisms across Earth. All living organisms (**Figure** 1.12 is a sampling) on Earth are descended from common ancestors.

Lesson Summary

- Science is a way of understanding (knowing) about the physical world that is based on evidence, reasoning, and testing predictions.
- A body of knowledge that has been thoroughly tested can still undergo further testing, and revisions as new evidence and questioning are raised.
- Science differs from other ways of knowing, because it is entirely based on observable evidence and its explanations are constantly questioned and tested.
- Science produces theories and general knowledge that allow us to better understand the world and to apply this knowledge to solve problems.

Review Questions

1. How is modern science different from other ways of knowing?
2. Explain why science cannot be used to examine whether someone is good or bad?
3. How is the scientific meaning of the word "theory" different from its use in day-to- day conversation?
4. What do all fields of life science have in common?
5. What are the three characteristics of evidence?
6. What is the goal of science?

Figure 1.12: Evolution explains the millions of varieties of organisms on Earth. (2)

7. What would you study if you were a biogeographer?

Further Reading / Supplemental Links

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Vocabulary

anecdotal evidence A description of an event that is used to make a point.

biogeography The study of the distribution of living organisms.

ecology The study of the interactions of organisms with each other and with their environment.

evidence Something that gives us grounds for knowing of the existence or presence of something else.

life science The study of living organisms and how they interact with each other and their environment.

population biology The study of the biodiversity, evolution, and environmental biology of populations of organisms.

science A way of knowing about the physical world, based on observable evidence, testing predictions, and reasoning.

science theories Well established and tested explanations of observations; produced through repeated studies, usually performed and confirmed by many individuals.

Points to Consider

- Next we are going to discuss the scientific method. You may have heard someone say that you can ruin your eyes if you sit too close to the television set.
- Describe how "thinking like a scientist" could help you figure out if this common sense idea is true or false.

1.2 Lesson 1.2: The Scientific Method

Lesson Objectives

- Consider how the scientific method is one of the most important reasons for how modern science is advancing more rapidly than in the past.
- Describe the scientific method as a process.
- Explain why the scientific method allows scientists and others to examine the physical world more objectively than other ways of knowing.
- Describe the steps involved in the scientific method.

Check Your Understanding

- What is science?
- What is a scientific theory?

Introduction

The **scientific method** is an inquiry process used to investigate the physical world using observable evidence and testing. This method allows scientists to "conduct" science in a uniform process. This process allows the information collected to be reproduced by other scientists, and most importantly, this process allows the information to be accepted and trusted.

Observations, Data, Hypotheses, and Experiments

Imagine that you are scientist who wants to know something like, "Why do whales migrate?" or "Why do some people get more colds than others do?" Two hundred years ago you could have come up with theories without necessarily thoroughly testing your ideas. But there were many exceptional scientists who made outstanding contributions. Here is a painting of Michael Faraday in his laboratory in the Royal Institution in England during the 1800s (**Figure** 1.13). Michael Faraday is best known for his contributions to chemistry, and he probably used some form of the scientific method to answer his questions.

Figure 1.13: Michael Faraday in his laboratory at the Royal Institution during the mid 1800s. (4)

As a modern scientist today, you would use the scientific method, collecting evidence to test your hypothesis and answer your questions. The scientific method presents a general idea of how science is conducted; it is not a strict pattern for doing research. Scientists use many different variations of the scientific method to meet their specific needs. Almost all versions of the scientific method include the following steps, though not always in the same order:

1. Make observations
2. Identify a question you would like to answer about the observation
3. Research: find out what is already known about your observation
4. Form a hypothesis
5. Test the hypothesis
6. Analyze your results
7. Communicate your results

A **hypothesis** is a proposed explanation that allows you to make predictions about what ought to happen if the hypothesis is true. If the predictions are accurate, that provides

support for the hypothesis. If the predictions are incorrect, that suggests the hypothesis is wrong.

Make Observations

Observe something in which you are interested. Here is an example of a real observation made by students in Minnesota (**Figure** 26.1). Imagine that you are one of the students who discovered this strange frog.

Figure 1.14: A frog with an extra leg. (21)

Imagine that you are on a field trip to look at pond life. While collecting water samples, you notice a frog with five legs instead of four. As you start to look around, you discover that many of the frogs have extra limbs, extra eyes or no eyes. One frog even has limbs coming out of its mouth. You look at the water and the plants around the pond to see if there is anything else that is obviously unusual like a source of pollution.

Identify a Question That is Based on Your Observations

The next step is to ask a question about these frogs. For example, you may ask why so many frogs are deformed. You may wonder if there is something in their environment causing these defects. You could ask if deformities are caused by such materials as water pollution, pesticides, or something in the soil nearby (**Figure** 1.15).

Yet, you do not even know if this large number of deformities is "normal" for frogs. What if many of the frogs found in ponds and lakes all over the world have similar deformities? Before you look for causes, you need to find out if the number and kind of deformities is unusual. So besides finding out *why* the frogs are deformed, you should also ask:

"Is the percentage of deformed frogs in pond A (your pond) greater than the percentage of deformed frogs in other places?"

Figure 1.15: A pond with frogs. (14)

Research Existing Knowledge About the Topic

No matter what you observe, you need to find out what is already known about your topic. For example, is anyone else doing research on deformed frogs? If yes, what did they find out? Do you think that you should repeat their research to see if it can be duplicated? During your research, you might learn something that convinces you to alter your question.

Construct a Hypothesis

A hypothesis is a proposed explanation of an observation. For example, you might hypothesize that a certain pesticide is causing extra legs. If that's true, then you can *predict* that the water in a pond of healthy non deformed frogs will have lower levels of that pesticide. That's a prediction you can test by measuring pesticide levels in two sets of ponds, those with deformed frogs and those with nothing but healthy frogs. A hypothesis is an explanation that allows you to predict what results you will get in an experiment or survey.

The next step is to state the hypothesis formally. A hypothesis must be "testable."

Example:

After reading about what other scientists have learned about frog deformities, you predict what you will find in your research. You construct a hypothesis that will help you answer your first question.

Any hypothesis needs to be written in a way that it can:

1. Be tested using evidence.
2. Be falsified (found false/wrong).
3. Provide measurable results.
4. Provide yes or no answers.

For example, the following hypothesis can be tested and provides yes or no answers:

"The percentage of deformed frogs in five ponds that are heavily polluted with a specific chemical X is higher than the percentage of deformed frogs in five ponds without chemical X."

Test Your Hypothesis

The next step is to count the healthy and deformed frogs and measure the amount of chemical X in all the ponds. This study will test the hypothesis. The hypothesis will be either true or false.

An example of a hypothesis that is not testable would be: "The frogs are deformed because someone cast a magic spell on them." You cannot make any predictions based on the deformity being caused by magic, so there is no way to test a magic hypothesis or to measure any results of magic. There is no way to prove that it is not magic, so that hypothesis is untestable and therefore not interesting to a scientist.

Analyze Data and Draw a Conclusion

If a hypothesis and experiment are well designed, the experiment will produce measurable results that you can collect and analyze. The analysis should tell you if the hypothesis is true or false.

Example:

Your results show that pesticide levels in the two sets of ponds are statistically different, but the number of deformed frogs is almost the same when you average all the ponds together. Your results demonstrate that your hypothesis is either false or the situation is more complicated than you thought. This gives you new information that will help you decide what to do next. Even if the results supported your hypothesis, you would probably ask a new question to try to better understand what is happening to the frogs and why. When you are satisfied that you have accurate information, you share your results with others.

You will probably revise your hypothesis and design additional experiments along the way.

Communicate Results

Scientists communicate their findings in a variety of ways. For example, they may discuss their results with colleagues, talk to small groups of scientists, give talks at large scientific meetings, and write articles for scientific journals. Their findings may also be communicated to journalists.

Example:

You eventually decide that you have strong results to share about frog deformities. You write an article and give talks about your research. Your results could contribute towards solutions.

Drawing Conclusions and Communicating Results

If a hypothesis and experiment are well designed, the results will indicate whether your hypothesis is true or false. If a hypothesis is supported by the results of a study, scientists will often continuing testing the hypothesis in new ways to learn more.

If a hypothesis is false, the results may be used to construct and test a new hypothesis. The next step is to analyze your results and to communicate them to other scientists. Scientific articles include the questions, methods and the conclusions from their research. Other scientists may try to repeat the experiments or change them. Scientists spend much time sharing and discussing their ideas with each other. Different scientists have different kinds of expertise they can use to help each other. When many scientists have independently come to the same conclusions, a scientific theory is developed. A scientific theory is a well-established explanation of an observation. In is generally accepted among the scientific community. Scientific theories are discussed in *The Nature of Science* Lesson.

Basic and Applied Science

Science can be "basic" or "applied." The goal of basic science is to understand how things work - whether it's why things fall on the floor or the structure of cells. Basic science is the source of most scientific theory and new knowledge. Applied science is using scientific discoveries to solve practical problems or to create new technologies.

Even though basic research is not intended to solve problems directly, basic research always provides the knowledge that applied scientists need to solve problems. For example, medicine and all that is known about how to treat patients is applied science based on basic research (**Figure** 1.16).

Figure 1.16: A healthy newborn being examined by a doctor. (23)

Lesson Summary

- The scientific method is an inquiry process used to investigate the physical world using observable evidence and testing.
- A hypothesis is a proposed explanation of an observation; it is used to test an idea.
- A theory is a well-established explanation of an observation. A hypothesis must be written in a way that can be tested, is falsifiable (to be able to prove that something is false), is measurable, and will help answer the original question.

Review Questions

1. How is a hypothesis different from a theory?
2. What does a hypothesis need to include?
3. What does "falsifiable" mean?
4. List the steps of the Scientific Method?
5. What is basic research?
6. What is applied research?
7. What does a scientist do if their research results conflict with previous theories or popular knowledge?
8. Is it OK for scientists to change their ideas?

Further Reading / Supplemental Links

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Vocabulary

applied science The application of science to practical problems.

basic science Research whose goal is just to find out how the world works, not to solve an urgent problem. Basic research is the source of most new scientific information and nearly all new theories.

falsifiable Testable. If a hypothesis generates predictions that can be shown to be true or false by experiment or observation, the hypothesis is "falsifiable" or "testable."

hypothesis A proposed explanation for something that is testable.

predict To say what will happen in a given situation. A scientific prediction is different from an everyday prediction, like predicting the weather before it happens. A scientific prediction is related to a specific hypothesis.

scientific method A careful way of asking and answering questions to learn about the physical world that is based on reason and observable evidence.

scientific theory A well-established set of explanations that explain a large amount of scientific information.

Points to Consider

- Next we consider the tools of the scientist.
- How do you think scientific "tools" can help a scientist?
- What do you think is one of the more common tools of the life scientist?

1.3 Lesson 1.3: Tools of Science

Lesson Objectives

- Describe the growing number of tools available to investigate different features of the physical world.
- Describe how microscopes have allowed humans to view increasingly small tissues and organisms that were never visible before.

Check Your Understanding

- What is the scientific method?
- What is an experiment?

Using Microscopes

Microscopes, tools that you may get to use in your class, are some of the most important tools in biology **Figure** 1.17 . Before microscopes were invented in 1595, the smallest things you could see on yourself were the tiny lines in your skin. The magnifying glass, a simple glass lens, was developed about 1200 years ago. A typical magnifying glass may have doubled the size of an image. But microscopes allowed people to see objects as small as individual cells and even large bacteria. Microscopes let people see that all organisms are made of cells. Without microscopes, some of the most important discoveries in science would have been impossible.

Microscopes are used to look at things that are too small to be seen by the unaided eye. **Microscopy** is a technology for studying small objects using microscopes. A microscope that magnifies something two to ten times (indicated by 2X or 10X on the side of the lens) may be enough to dissect a plant or look closely at an insect. Using even more powerful microscopes, scientists can magnify objects to two million times their real size.

Some of the very best early optical microscopes were made four hundred years ago by Antoine van Leeuwenhoek (**Figure** 1.18), a man who taught himself to make his own microscopes (**Figure** 1.19). When he looked at a sample of scum from his own teeth, Leeuwenhoek discovered bacteria. In rainwater, he saw tiny protozoa. Imagine his excitement when he looked through the microscope and saw this lively microscopic world. van Leeuwenhoek discovered the first one-celled organisms (protists), the first bacteria, and the first sperm. Robert Hooke, an English natural scientist of the same period of history, used a microscope to see and name the first "cells" (**Figure** 1.20), which he discovered in plants.

Some modern microscopes use light, as Hooke's and van Leeuwenhoek's did, but others may use electron beams or sound waves.

Researchers now use four kinds of microscopes:

1. **Light microscopes** allow biologists to see small details of biological specimens. Most of the microscopes used in schools and laboratories are light microscopes. Light microscopes use refractive lenses, typically made of glass or plastic, to focus light either into the eye, a camera, or some other light detector. The most powerful light microscopes can magnify images up to 2,000 times. Light microscopes are not as powerful as other higher tech microscopes but they are much cheaper and anyone can own one and see many amazing things.
2. **Transmission electron microscopes** (TEM) focus a beam of electrons through an

Figure 1.17: Basic light microscopes opened up a new world to curious people. 1, ocular lens or eyepiece; 2, objective turret; 3, objective lenses; 4, coarse adjustment knob; 5, fine adjustment knob; 6, object holder or stage; 7, mirror or light (illuminator); 8, diaphragm and condenser. (11)

Figure 1.18: Antoine van Leeuwenhoek, a Dutch cloth merchant with a passion for microscopy. (1)

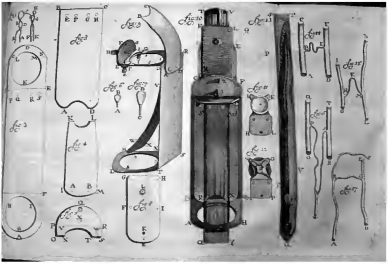

Figure 1.19: Drawing of microscopes owned by Antoine van Leeuwenhoek. Bacteria were discovered in 1683 when Antoine Van Leeuwenhoek used a microscope he built to look at the plaque on his own teeth. (12)

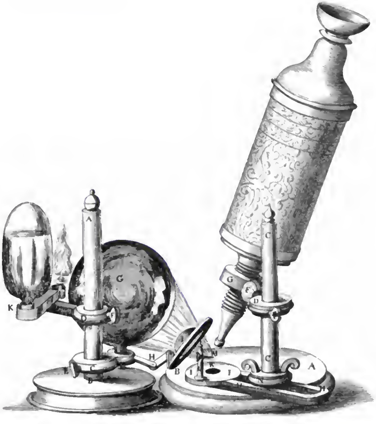

Figure 1.20: Robert Hooke's early microscope. (19)

object and can magnify an image up to two million times with a very clear image ("high resolution").

3. **Scanning electron microscopes** (SEM) (**Figure** 1.21) allow scientists to map the surfaces of extremely small objects. These microscopes slide a beam of electrons across the surface of specimen, producing detailed maps of the shapes of objects.
4. **Scanning acoustic microscopes** use sound waves to scan a specimen. These microscopes are useful in biology and medical research.

Figure 1.21: A scanning electron microscope. (6)

Other Life Science Tools

What other kinds of tools and instruments would you expect to find in a biologist's laboratory or field station? Other than computers and lab notebooks, biologists use very different

instruments and tools for the wide range of life science specialties. For example, a medical research laboratory and a marine biology field station might not use any of the same tools. Tools such as a radiotelemetry device (**Figure** 1.22), or a thermocycler (**Figure** 1.23) and even a fume hood (**Figure** 1.24) are all biological equipment.

Figure 1.22: A radiotelemetry device used to track the movement of seals in the wild. (22)

Using Maps and Other Models

You use models for many purposes. A volcano model, is not the same as a volcano, but it is useful for thinking about real volcanoes. We use street maps to represent where streets are in relation to each other. A model of planets may show the relationship between the positions of planets in space. Biologists use many different kinds of models to simulate real events and processes. Models are often useful to explain observations and to make scientific predictions.

Some models are used to show the relationship between different variables. For example, the model in **Figure** 26.4 says that when there are few coyotes, there are lots of rabbits (left side of the graph) and when there are only a few rabbits, there are lots of coyotes (right side of the graph). You could make a prediction, based on this model, that removing all the coyotes from this system would result in an increase in rabbits. That's a prediction that can be tested.

Figure 1.23: A thermocycler used for molecular biological and genetic studies. (17)

Figure 1.24: A laboratory fume hood. This laboratory hood sucks dangerous fumes out of a lab and allows researchers to work with dangerous chemicals without breathing them. (27)

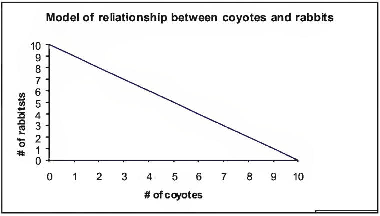

Figure 1.25: This graph shows a model of a relationship between a population of coyotes (the predators) and a population of rabbit, which the coyotes are known to eat (the prey). (18)

Lesson Summary

- From the time that the first microscope was built, over four hundred years ago, microscopes have been used to make major discoveries.
- Life science is a vast field; different kinds of research usually require very different tools.
- Basic research produces knowledge and theories; applied research uses knowledge and theories from basic research to develop solutions to practical problems.
- Scientists use maps and models to understand how features of real events or processes work.

Review Questions

1. What did van Leeuwenhoek discover when he looked at plaque from his own teeth under the microscope?
2. What does the symbol 10X on the side of a microscope mean?
3. What is a scientific model?
4. Look at the predator/prey (coyote/rabbit) model again. What does the model predict would happen to the rabbit population if you took away all the coyotes?
5. How long ago were the first microscopes invented?
6. What tool would you use to keep track of where a wolf travels?
7. What is the relationship between basic and applied research?

Vocabulary

applied research Research designed for the purpose of producing results that may be applied to real world situations.

basic research Research to gain new knowledge about the basic processes of life, including how the body works; but the goal is not a commercial application.

electron microscopes Used to create high magnification (magnified many times) and high resolution (very clear) images.

microscopes A set of lenses used to look at things too small to be seen by the unaided eye.

microscopy All the methods for studying things using microscopes.

optical (light) microscopes A microscope that focuses light, usually through a glass lens; used by biologists to small details of biological specimens.

scanning acoustic microscopes A microscope that focuses sound waves instead of light.

scanning electron microscopes A microscope that scans the surfaces of objects with a beam of electrons to produce detailed images of the surfaces of tiny things.

Points to Consider

- What could be some hazards that biologists may face in the laboratory?
- What could be risks of doing field research?
- So what do you think biologists do to protect themselves?

1.4 Lesson 1.4: Safety in Scientific Research

Lesson Objectives

- Recognize how the kind of hazards that a scientist faces depends on the kind of research they do.
- Identify some potential risks associated with scientific research.
- Identify who and what safety regulations are designed to protect.

Check Your Understanding

- What is the scientific method?

Introduction

There are some very serious safety risks in scientific research. Research can involve many different kinds of risks. Yet, if science were as dangerous as some horror movies make it look, not many people would become scientists. Since the life sciences deal with living organisms, some research may have risks not found in other fields. Safety practices are needed to work with any potentially hazardous situation, such as:

- pathogenic (disease-causing) viruses, bacteria or fungi
- parasites
- wild animals
- radioactive materials
- pollutants in air, water, or soil
- toxins
- teratogens
- carcinogens
- radiation

The kinds of risks that scientists face depend on the kind of research they perform. For example, a bacteriologist working with bacteria in a laboratory faces different risks than a zoologist studying the behavior of lions in Africa. Think back to the deformed frogs discussed earlier, the ones in the pond with extra limbs or extra eyes. If there is something in the frogs' environment causing these deformities, could there be a risk to a researcher in that environment? A chemical in the pond that could cause such deformities is called a "teratogen." Or perhaps a disease is causing the deformities. Infectious agents such as viruses and bacteria are called **biohazards** (**Figure** 1.26). Biohazards include any material such as medical waste that could possibly transmit an infectious disease. A used hypodermic needle or a vial of bacteria are both biohazards.

Laboratory Safety

Most laboratories are safe places to visit. If you plan to work in a scientific laboratory, ask someone to tell you about the safety rules they are required to follow. Scientists must follow regulations set by federal, state, and private institutions. For example, scientists cannot work with hazardous materials or equipment without:

- Getting approval to do the specific research.

Figure 1.26: The Biohazard symbol. (24)

- Using safety equipment, such as hoods and fans (**Figure** 1.27 and **Figure** 1.28).
- Demonstrating that the staff are familiar with risks, know how to respond to problems, and can follow safety regulations.
- Accepting laboratory inspections by safety officers at any time.

Figure 1.27: An example of a science laboratory workbench. A fume hood is on the left. (28)

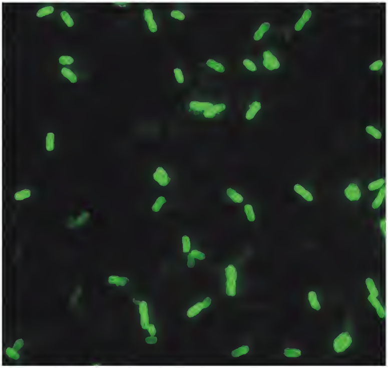

Figure 1.28: Scientists studying dangerous organisms such as *Yersinia pestis*, the cause of bubonic plague, use special equipment that helps keep the organism from escaping the lab. (16)

Field Research Safety

Scientists who work in the outdoors, called "field scientists," are also required to follow safety regulations designed to prevent harm to themselves, other humans, to animals, and the environment.

Scientists are required to follow the same level of safety standards in the field as they do in a laboratory. In fact, if scientists work outside the country, they are required to learn about and follow the laws and restrictions of the country in which they are doing research. For example, entomologists following monarch butterfly (**Figure** 1.29) migrations between the United States and Mexico would have to follow regulations in both countries.

Figure 1.29: A Monarch Butterfly (29)

Field scientists are also required to follow laws to protect the environment. Before biologists can study protected wildlife or plant species, they must apply for permission to do so, and obtain a research permit, if required.

Lesson Summary

- Research of any kind may have safety risks. Because biologists study living organisms as diverse as bacteria and bears, they deal with risks that other scientists may never encounter.
- The risks scientists face depend on the kind of research they are doing.
- Scientists are required by federal, state, and local institutions to follow strict regulations designed to protect the safety of themselves, the public, and the environment.

Review Questions

1. What kinds of hazards might be found in biology laboratories, but not physics laboratories?
2. Who has more freedom to do whatever research they want? Laboratory scientists or field biologists?
3. What is a biohazard?
4. What is a research permit?
5. What are some of the precautions you might take if you were collecting frogs in water you think might be polluted?
6. Name some possible hazards to field biologists.
7. If a scientist does research in a foreign country, which research laws would the scientist need to follow: those of the homeland or the foreign country?

Further Reading / Supplemental Links

Biosafety in Microbiological and Biomedical Laboratories (National Research Council, 1999).

Chemical Classification Signs:

- http://www.howe.k12.ok.us/~jimaskew/nfpa.htm

NFPA Chemical Hazard Labels:

- http://www.atsdr.cdc.gov/NFPA/nfpa_label.html

Where to Find MSDS's on the Internet:

- http://www.ilpi.com/msds/index.html

Cornell University MSDS:

- http://msds.pdc.cornell.edu/msdssrch.asp

MSDS Power Point:

- http://www.tenet.edu/teks/science/safety/pdf/hazcom/msds.ppt

- http://www.research.northwestern.edu/ors/biosafe/index.htm

Vocabulary

anecdotal evidence A description of an event that is used to make a point.

applied research Research designed for the purpose of producing results that may be applied to real world situations.

basic research Research to gain new knowledge about the basic processes of life, including how the body works normally; but the goal is not a commercial application.

biohazard Is any biological material, such as infectious material that poses a potential to human health, animal health, or the environment.

evidence Something used to clearly determine or demonstrate the truth of an assertion.

falsifiable Confirmable; capable of being tested (verified or falsified) by experiment or observation.

hypothesis A concept that is not yet verified but that if true would explain certain facts or phenomena.

pathogen A disease causing agent.

scientific model Something used to represent feature a real system or item.

theory An explanation for an event that is based on observation, experimentation, and reasoning.

Points to Consider

- We are now moving into examining living things.
- What do you think makes something "alive?"
- What may be some things a blade of grass, a fly, and you have in common?

Image Sources

(1) http://en.wikipedia.org/wiki/Image:Antoni_van_Leeuwenhoek.png. Public Domain.

(2) *Evolution explains the millions of varieties of organisms on Earth.*. CC-BY-SA 3.0.

(3) http://en.wikipedia.org/wiki/File:Chopping_Board.jpg. GNU-FDL.

(4) *M_Faraday_Lab_H_Moore.jpg* . Public Domain.

(5) Robert A. Thom. *[Wikipedia]*. Public Domain.

(6) *A scanning electron microscope.*. GNU-FDL.

(7) *A mouse cell viewed through a microscope.*. GNU-FDL.

(8) NASA. ***The Phylogenetic Tree of Life***. Public Domain.

(9) *A male lion.*. CC-BY 2.0.

(10) NCBI. http://commons.wikimedia.org/wiki/File:Celltypes.svg. Public Domain.

(11) http://en.wikipedia.org/wiki/Image:Optical_microscope_nikon_alphaphot.jpg. Public Domain.

(12) http://en.wikipedia.org/wiki/Image:Van_Leeuwenhoek%27s_microscopes_by_Henry_Baker.jpg. Public Domain.

(13) USGS. http://en.wikipedia.org/wiki/Image:WNVUSAMap.png. GNU-FDL.

(14) *A pond with frogs.*. GNU-FDL.

(15) *A Humpback whale.*. GNU Free Documentation.

(16) http://en.wikipedia.org/wiki/Black_Death. Public Domain.

(17) http://commons.wikimedia.org/wiki/Image:Pcr_machine.jpg. Public Domain.

(18) Talia Karasov. . CC-BY-SA.

(19) *Robert Hooke's early microscope.*. Public Domain.

(20) *Humboldt1805-chimborazo.jpg* . Public Domain.

(21) USGS. *A frog with an extra leg.*. Public Domain.

(22) http://en.wikipedia.org/wiki/File:Phoca_vitulina_Telemetry.jpg. CC-BY-SA 2.5.

(23) *A healthy newborn being examined by a doctor.*. GNU-FDL.

(24) *The Biohazard symbol.*. Public Domain.

(25) NIH. Escherichia coli *bacteria*. Public Domain.

(26) *The_Anatomy_Lesson.jpg* . Public Domain.

(27) `http://commons.wikimedia.org/wiki/File:Fume_hood.jpg`. Public Domain.

(28) `http://upload.wikimedia.org/wikipedia/commons/5/5f/Lab_bench.jpg`. CC-BY 1.0.

(29) Derek Ramsey. *A Monarch Butterfly*. GNU-FDL.

Chapter 2

Introduction to Living Organisms

2.1 Lesson 2.1: What are Living Things?

Lesson Objectives

- List the defining characteristics of living things.
- List the needs of all living things.

Check Your Understanding

- How do life scientists study the natural world?
- Are scientific theories just a "hunch" or a hypothesis?

Introduction

How would you define a living thing? In other words, what do mushrooms, daisies, cats, and bacteria have in common? (The series of pictures in the **Figure** 2.1 are additional representations.) All of these are living things, or **organisms.** It might seem hard to think of similarities among such diverse organisms, but there are actually many similarities. The chemical processes inside all organisms are the same. For example, all living things encode their genetic information in the same way. And many organisms share the same needs, such as the need for energy and materials to build their bodies. Living things have so many similarities because all living things have evolved from the same common ancestor that lived billions of years ago.

All living organisms:

- Need energy to carry out life processes
- Are composed of one or more cells (the cell theory)
- Evolve and share an evolutionary history
- Respond to their environment
- Grow, reproduce themselves, and pass on information to their offspring in the form of genes
- Maintain a stable internal environment (homeostasis)

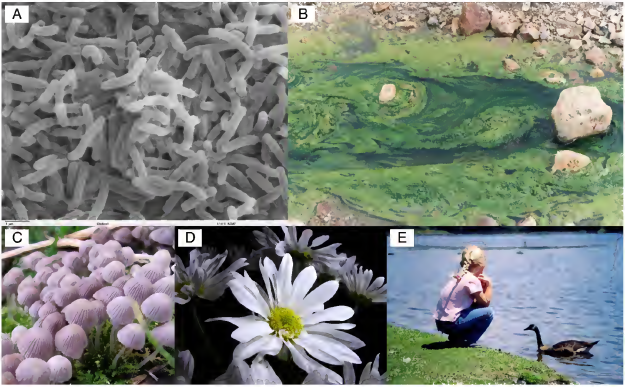

Figure 2.1: Life on Earth is very diverse, yet all these forms of life share some characteristics. Forms of life include: A) Bacteria, B) Algae, C) Fungi, D) Plants, and E) Animals. (13)

Living Things Maintain Stable Internal Conditions

All living things have some ability to maintain a stable internal environment. The inside of an organism is separate and different from the outside world. Maintaining that separation and difference is known as **homeostasis.** For example, many animals work hard to keep their temperature within a certain range. If the animal gets too hot or too cold, it will die. As a result, many animals have evolved behaviors that regulate their internal temperature. A lizard may stretch out on a sunny rock to increase its internal temperature, and a bird may fluff its feathers to stay warm (**Figure** 2.2).

Figure 2.2: A bird fluffs his feathers to stay warm (keep from losing energy) and to maintain homeostasis. (6)

Mammals and birds are **homeotherms**–meaning they maintain the same temperature most of the time. A lizard or an earthworm is a **heterotherm**, meaning its temperature can change.

Humans and other mammals may deliberately do things to stay warm or to cool off, like lie down under a shady tree. But most mammals maintain a steady temperature primarily through unconscious processes. A portion of your unconscious brain regulates your body temperature. If you get too warm, you start to sweat and the blood vessels in your skin open up to let the blood flow to the surface of your body. If you are too cold, you start to shiver and the blood supply to your skin, hands and feet may be reduced.

There are many forms of homeostasis besides temperature regulation. For example, when you have a big lunch, your body produces the hormone insulin, which helps maintain the right amount of sugar in your blood. Meanwhile, your kidneys are hard at work maintaining the right amount of water and salts in your blood. Both of these processes happen unconsciously and are part of homeostasis.

Living Things Grow and Reproduce

All living things reproduce. Organisms that do not reproduce go extinct, every time. As a result, there are no species that do not reproduce.

Reproduction, the process of creating a new organism, is different for different organisms. Many organisms reproduce sexually, where an egg and sperm go together to form a new

Figure 2.3: Like all living things, cats reproduce themselves and make a new generation of cats. When animals and plants reproduce they make tiny undeveloped versions of themselves called **embryos**, which grow up and develop into adults. A kitten is a partly developed cat. (22)

individual. (Cats are one such species, **Figure** 2.3.) Other organisms can reproduce without sex ("asexually"). For example, bacteria can simply split in two, producing two identical new cells. But it's not just bacteria that can reproduce without sex. Some lizards can produce clones of themselves. In such species, all individuals are female and simply lay their eggs when they are ready to reproduce. During all reproduction, the parents pass genetic information to their offspring, a process called **heredity**. Heredity is the passing of genes to the next generation. These genes influence all the traits of an organism, including overall body shape, size, whether it has fur or feathers, teeth or a beak, eye color, and so on. This genetic information is essential to an organism. In all organisms made of cells, this genetic information comes in the form of **deoxyribonucleic acid**, or DNA, which we will discuss in lesson 2. (In viruses, which are not made of cells, the genetic information is sometimes in the form of RNA, a different nucleic acid.) DNA contains the "instructions" for building important molecules inside of cells.

Living Things are Composed of Cells

All living things are composed of cells (**Figure** 2.4), the tiny units that are the building blocks of life. Cells are the smallest possible unit of life that is still considered living. Most cells are so small that they are usually visible only through a microscope. Some organisms, like the tiny plankton that live in the ocean, are composed of just one cell (**Figure** 2.5).

Other organisms have many millions of cells that make up different body tissues and organs. On the other hand, eggs are some of the biggest cells around, including chicken eggs and ostrich eggs. But most cells are tiny.

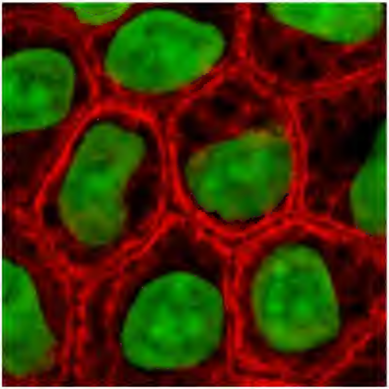

Figure 2.4: **Skin cells.** All living organisms are made of one or more cells. (18)

All cells share at least some structures. But there are thousands of kinds of cells with different structures. The cells of plants and mushrooms have a cell wall, while the cells of animals do not. The cells of most organisms have a special membrane around the DNA, but bacterial cells do not. Although the cells of different organisms are built differently, they all function much the same way. Every cell must get energy from food, be able to grow and reproduce, and respond to its environment.

Living Things Need Resources and Energy

In order to grow, reproduce, and maintain homeostasis, living things need energy. The work you do each day, from walking to writing and thinking, is fueled by energy in your cells. But where does this energy come from?

The source of energy differs for each type of living thing. In your body, the source of energy is the food you eat. All animals must eat plants or other animals in order to obtain energy and building materials. Plants themselves don't eat; they use the energy of the sun to

Figure 2.5: This paramecium is a one-celled organism. (9)

make their "food" through the process of photosynthesis (see *Cell Functions* chapter). Like animals, mushrooms and other fungi obtain energy from other organisms. That's why you often see fungi growing on a fallen tree; the rotting tree is their source of energy (**Figure** 2.6). Although the means of getting energy might be different, all organisms need some source of energy. And since plants harvest energy from the sun and other organisms get their energy from plants, nearly all the energy of living things ultimately comes from the sun.

Figure 2.6: Fungi obtain energy from breaking down dead organisms, such as this rotting log. (25)

Besides obtaining energy from the foods you eat, you also need the chemical building blocks in food to build and maintain your body. For example, you get calcium for building bones from eating dairy products or leafy greens. Plants obtain nutrients from the soil. Nutrients will be discussed in the next lesson.

Lesson Summary

- All living things grow, reproduce, and maintain a stable internal environment.
- All organisms are made of cells.
- All living things need energy and resources to survive.

Review Questions

1. Define the word organism.

2. Give two examples of processes that help organisms achieve homeostasis.
3. What are three characteristics of living things?
4. What are a few ways organisms can get the energy they require?
5. What is a cell?

Further Reading / Supplemental Links

- http://publications.nigms.nih.gov/thenewgenetics/thenewgenetics.pdf
- http://en.wikipedia.org

Vocabulary

cell The smallest living unit of life; the smallest unit of structure of living organisms.

DNA Deoxyribonucleic acid; the heredity material; carries the genetic information of the cell.

heredity The passing of traits or a tendency to certain traits to the next generation through units of inheritance called genes.

homeostasis Maintaining a stable internal environment despite changes in the environment.

organism A living thing.

reproduction The process by which an organism makes a new organism with at least some of its own genes.

Points to Consider

- DNA is considered the "instructions" for the cell. What do you think this means?
- What kinds of chemicals do you think are necessary for life?
- Do you expect that the same chemicals can be in non-living and living things?

2.2 Lesson 2.2: Chemicals of Life

Lesson Objectives

- Distinguish between an element and a compound.

- Explain how elements are organized on the periodic table.
- Explain the function of enzymes.
- Name the four main classes of organic molecules that are building blocks of life.

Check Your Understanding

- What are the main properties of all living things?
- What is homeostasis?

Introduction

Physical science and biology are two different subjects in school, so you might see them as two unrelated sciences. However, understanding physical science is essential for understanding biology. Living things are subject to the same physical laws of the universe as non-living things. The rules that apply to chemical reactions in a test tube also apply to the chemical reactions that take place inside your body. To understand how living things function, we must have a little knowledge of physics and chemistry. This includes knowing what elements are and how different molecules come together to form the components of life.

The Elements

Rocks, animals, flowers, and even your body, are made up of matter. **Matter** is anything that takes up space and has mass. Matter makes up everything, living and nonliving.

Matter is composed of a mixture of elements. **Elements** are substances that cannot be broken down into simpler substances with different properties. Even chemical reactions or physical processes, like heating or crushing, cannot break it down to release a simpler substance. There are more than 100 known elements, and 92 occur naturally around us. The others have been made only in the laboratory.

Elements are made up of identical atoms. An **atom** is the simplest and smallest particle of matter that still retains the chemical properties of the element. Atoms are so tiny that only the most powerful microscopes can detect them. Atoms are the building block of all elements, and of all matter. Each element has a different type of atom, and is represented with a one or two letter symbol. For example, the symbol for oxygen is O and the symbol for carbon is C.

Atoms themselves are composed of even smaller particles, including: the positively charged **protons**, the uncharged **neutrons**, and the negatively charged **electrons**. Protons and neutrons are located in the center of the atom, or the nucleus, and the electrons move around the nucleus. How many protons and neutrons an atom has determines what element it is. For example, Helium (He) always has two protons (**Figure** 2.7), while Sodium (Na)

always has 11. To restate this, all the atoms of a particular element have the exact same number of protons, and the number of protons is that element's **atomic number**.

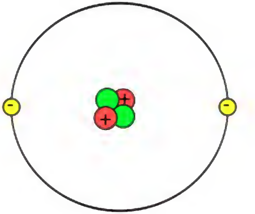

Figure 2.7: An atom of Helium (He) contains two positively charged protons (red), two uncharged neutrons (green), and two negatively charged electrons (yellow). (17)

The Periodic Table

Each element also has unique properties, such as density, boiling point, and how well it dissolves ("solubility"). **Density** is the mass of the substance per unit of volume. That means that if you take an equal volume of different elements, each different sample will weigh a different amount. For example, a liter of the metal mercury weighs 13 times as much as a liter of water. The **boiling point** is the temperature at which an element will change from a liquid to a gas. For example, the boiling point of water is 100 degrees Celsius. Once you heat water to this temperature, you see bubbles form as the water turns into vapor. Each element has a different boiling point. **Solubility** is how well a substance will dissolve in water. You can dissolve more sugar in a liter of water than salt, because sugar is more soluble than salt. Density, boiling point, and solubility have unchanging values for each element.

In 1869, Dmitri Mendeleev constructed the periodic table in 1869, organizing all the elements according to their atomic number, density, boiling point, solubility, and other values. As mentioned above, each element has a one or two letter symbol. For example, H stands for hydrogen and Au for gold. The vertical columns in the periodic table are known as groups and elements in groups tend to have very similar properties. The table is also divided into rows, known as periods.

Group 1 (see **Figure** 2.8) contains the highly reactive metals, such as sodium (Na) and lithium (Li). Just a small amount of these metals will explode into flames when put into water. Another group are the less-reactive metals, such as gold (Au) and platinum (Pt). Since they will not react readily with air and tarnish, these metals are highly valued for

making jewelry. There are also highly reactive nonmetals, such as chlorine and oxygen, and some nonreactive gases, such as helium (He) and neon (N), which you might recognize from helium balloons and neon signs.

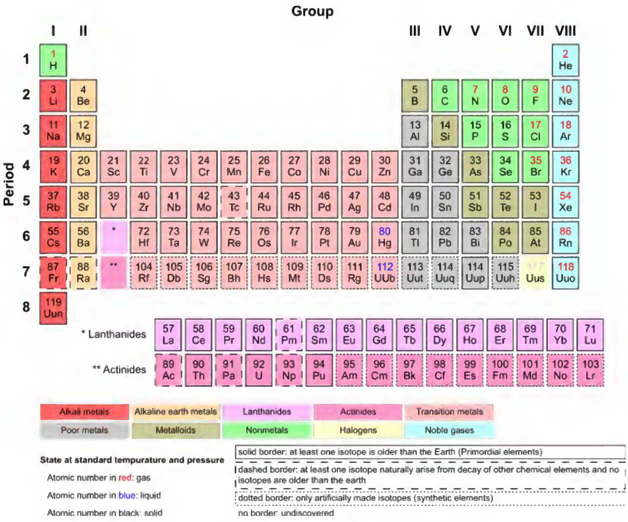

Figure 2.8: The periodic table groups the elements based on their properties. (30)

Chemical Reactions

A **molecule** is any combination of two or more atoms. The oxygen in the air we breathe is two oxygen atoms connected by a chemical bond to form O_2, or molecular oxygen. A carbon dioxide molecule is a combination of one carbon atom and two oxygen atoms. Because carbon dioxide includes two different elements it is a "compound" as well as a molecule.

A **compound** is any combination of two or more elements. A compound usually has very different properties from the elements that it contains. Elements and combinations of elements

make up all the diverse types of matter in the universe.

The process by which two different elements come together to form a compound is one example of a **chemical reaction**. For example, hydrogen and oxygen together form water. Water has the properties of a liquid, not the properties of the gases hydrogen and oxygen. Water is the **product**, or end result, of the chemical reaction while hydrogen and oxygen are the **reactants**, or "ingredients" necessary for the chemical reaction.

One important chemical reaction in your everyday life is oxidation, or the combination of oxygen and another element. Examples of oxidation are burning and rusting. When oxygen combines with gas on your stove top, the reaction releases heat that you can use to cook with. (In fact, since fires need oxygen to burn, most fire extinguishers are composed of heavier gasses that will displace the oxygen, smothering the fire.) Rust is formed when oxygen combines with iron (**Figure** 2.9). These are a few examples of chemical reactions.

Figure 2.9: Rust is the result of a chemical reaction between iron and oxygen. (16)

Organic Compounds

The chemical components of living things are known as **organic compounds**, which means they contain the element carbon (C). Living things are made up of compounds that are quite large. These large compounds molecules, known as **macromolecules**, are made of smaller molecules. You might recognize some of these organic molecules as parts of the food you eat (**Figure** 2.16). Through eating food, we obtain the organic molecules we need to grow and be healthy.

Table 2.1: **The Four Main Classes of Organic Molecules**

	Proteins	Carbohydrates	Lipids	Nucleic Acids
Elements	C,H,O,N,S	C,H,O	C,H,O,P	C,H,O,P,N
Examples	Enzymes, muscle fibers, antibodies	Sugar, Starch, Glycogen, Cellulose	Phospholipids in membranes, fats, oils, waxes, steroids	DNA, RNA, ATP
Monomer (small building block molecule)	Amino acids	Sugars	Often include fatty acids	Nucleotides

Organic compounds all contain the elements carbon (C) and hydrogen (H). The chain of carbon and hydrogen in organic compounds is sometimes called the "backbone" of organic compounds since they make up the core center structure. What makes organic compounds different from one another is the **functional groups**, groups of atoms that have unique chemical properties. The addition of a functional group vastly changes the properties of the carbon-hydrogen backbone of organic compounds. Each organic compound is therefore suited to its unique role in living things.

Carbohydrates

Essentially, carbohydrates are sugars or long chains of sugars. An important role of **carbohydrates** is to store energy. Glucose is a simple sugar molecule with the chemical formula $C_6H_{12}O_6$. Sugar is one type of carbohydrate, but carbohydrates also include long chains of connected sugar molecules. These chains of sugar molecules can be used to store sugar for later use, such as in the form of starches or glycogen. Plants store sugar in long chains called *starch*, whereas animals store sugar in long chains called *glycogen*. Both storage molecules contain hundreds or thousands of linked glucose molecules. Chains of sugar molecules also can be used as structural molecules. For example, the hard skeletons of insects and lobsters are made of chitin, a type of carbohydrate. These long chains of sugar molecules are know as **polysaccharides**. You get the carbohydrates you need for energy from eating carbohydrate-rich foods, including fruits and vegetables, as well as grains such as bread, rice, or corn.

The chemical formula $C_6H_{12}O_6$ of glucose means that this molecule has 24 atoms: 6 carbon atoms, 12 hydrogen atoms, and 6 oxygen atoms. Carbohydrates have a general chemical formula consisting of twice as many hydrogen atoms as carbon and oxygen atoms. Glucose is a **monomer**, a single unit that when linked together with other monomers forms a long chain known as a polymer. Starch is an example of a polymer.

Proteins

Proteins have many different functions in living things. Enzymes are a type of protein. **Antibodies** that protect your body from disease are proteins, and your muscles are made of protein. All proteins are made of monomers (small building block molecules) called amino acids that line up to form long chains. There are only 20 common amino acids. These amino acids have the general chemical formula $H_2NCHRCOOH$, where R is a "side group" which varies between amino acids. It is this side group that gives the amino acids its physical and chemical properties. These amino acids form in thousands of different combinations, generating up to 100,000 unique proteins. Proteins can differ in both the number and order of amino acids. Small proteins have just a few hundred amino acids, whereas the largest proteins have over 25,000 amino acids.

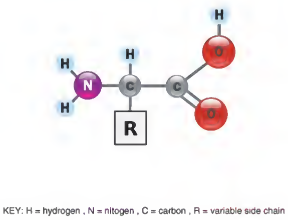

Figure 2.10: General Structure of Amino Acids. This model shows the general structure of all amino acids. Only the side chain, R, varies from one amino acid to another. For example, in the amino acid glycine, the side chain is simply hydrogen (H). In glutamic acid, in contrast, the side chain is CH_2CH_2COOH. Variable side chains give amino acids acids different chemical properties. The order of amino acids, together with the properties of the amino acids, determines the shape of the protein, and the shape of the protein determines the function of the protein. KEY: H = hydrogen, N = nitrogen, C = carbon, O = oxygen, R = variable side chain (29)

After a cell makes a protein chain, the chain folds into a 3-dimensional structure (**Figure** 2.11). Proteins fold based on the sequence and properties of the amino acids. The properties of amino acids can vary widely, so the position of each amino acid in a protein is important. Each folded protein has its own unique shape. It is this shape that gives the protein its function. The primary structure of a protein is the linear sequence of amino acids. The

amino acids appear as "beads on a string," as shown in the figure below. The folding of the protein into the 3-dimensional working molecule is based on the initial primary sequence of amino acids.

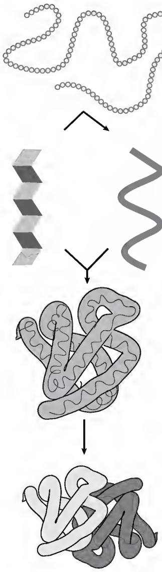

Figure 2.11: Proteins fold into unique 3-dimensional structures, starting with the linear "beads on a string," shown at the top, to the complex structure on the bottom. (14)

It's important for you and other animals to eat food with protein because we cannot synthesize some of these amino acids ourselves. You can get proteins both from plant sources such as beans and from animal sources, like milk or meat. When you eat food with protein, your body breaks the proteins down into individual amino acids and uses them to build new proteins. Therefore, you really are what you eat!

Lipids

The lipids - the fats, oils, and waxes - are a diverse group of organic compounds. **Lipids** are not soluble in water. (As you probably know, oil and water don't mix.) The most common lipids in your diet are probably fats and oils. Fats are solid at room temperature, whereas oils are fluid. Animals use fats for long-term energy storage and insulation. Plants use oils for long-term energy storage. When preparing food, we often use animal fats, such as lard and butter, or plant oils, such as olive oil or canola oil.

There are many more type of lipids that are important to life. One of the most important are the **phospholipids** (see the chapter titled *Cell Functions*) that make up the membranes that surround all cells. **Steroids** are the basis for the hormones like testosterone and estrogen. **Waxes** are useful lipids for plants and animals since they are waterproof. Plants coat their leaves in a waxy covering to prevent water loss, while bees use wax to make their honeycombs.

Nucleic acids

Nucleic acids are long chains of **nucleotides**, which are units composed of a sugar, a nitrogen-containing base, and a phosphate group. Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) are the two main nucleic acids. DNA is the molecule that stores our genetic information and RNA is involved in making proteins. Nucleotides also make up the high-energy molecule Adenosine Triphosphate (**ATP**). ATP is the energy currency of the cell. Every time you think a thought or move a muscle, you are using the energy stored in ATP.

The following series of **Figures** 2.12, 2.13, 2.14 and 2.15 show examples.

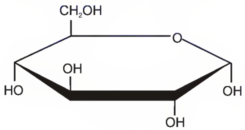

Figure 2.12: (A) A molecule of glucose (a carbohydrate). (4)

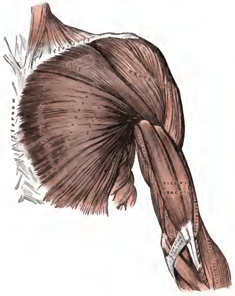

Figure 2.13: (B) Muscle fibers (protein). (31)

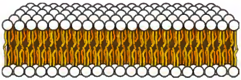

Figure 2.14: (C) Phospholipids in a membrane (lipid). (12)

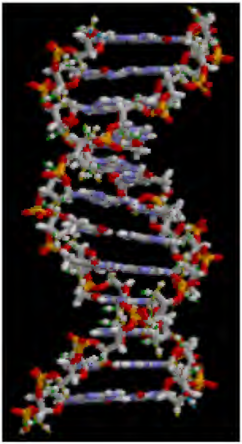

Figure 2.15: (D) DNA (nucleic acid). (3)

The

Figure 2.16: A healthy diet includes protein, fat, and carbohydrate. (27)

Enzyme Reactions

The oxidation reaction occurs readily, but not all reactions move so quickly. Others can take quite a while. Since many of the body's necessary chemical reactions would take years to happen on their own, you need the help of enzymes. **Enzymes** speed up chemical reactions, often by bringing the reactants closer together so they can interact more easily (**Figure** 2.17). Enzymes attach to, or **bind**, specifically to the reactants. Because enzymes are so specific, you have a different enzyme for every chemical reaction in your body. A single cell may contain hundreds or thousands of different enzymes.

When an enzymes attaches, or binds, to another molecule, that molecule is referred to as the **substrate**. The enzyme is usually much bigger than the substrate.

How Enzymes Work

How do enzymes speed up biochemical reactions so dramatically? Like all catalysts, enzymes work by lowering the activation energy of chemical reactions. This is illustrated in **Figure** 2.18. The biochemical reaction shown in the figure requires about three times as much energy without the enzyme as it does with the enzyme. An animation of this process can be viewed at http://www.stolaf.edu/people/giannini/flashanimat/enzymes/transition%20state.swf.

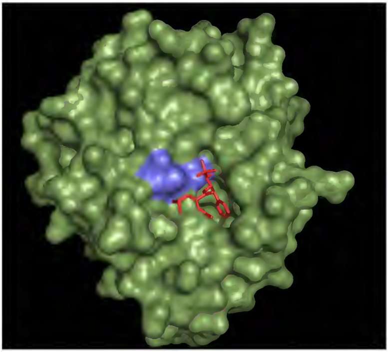

Figure 2.17: The enzyme (green) binds to the substrate (red) to speed up a chemical reaction. (26)

As discussed above, enzymes lower activation energy by reducing the energy needed for reactants to come together and react. For example:

- Enzymes bring reactants together so they don't have to expend energy moving about until they collide at random. Enzymes bind both reactant molecules (called substrate), tightly and specifically, at a site on the enzyme molecule called the active site (**Figure** 2.19).
- By binding reactants at the active site, enzymes also position reactants correctly, so they do not have to overcome the forces that would otherwise push them apart. This allows the molecules to interact with less energy.

The activities of enzymes also depend on the temperature, ionic conditions, and the pH of the surroundings.

Some enzymes work best at acidic pHs, while others work best in neutral environments.

- Digestive enzymes secreted in the acidic environment (low pH) of the stomach help break down proteins into smaller molecules. The main digestive enzyme in the stomach is pepsin, which works best at a pH of about 1.5 (see the *Digestive and Excretory*

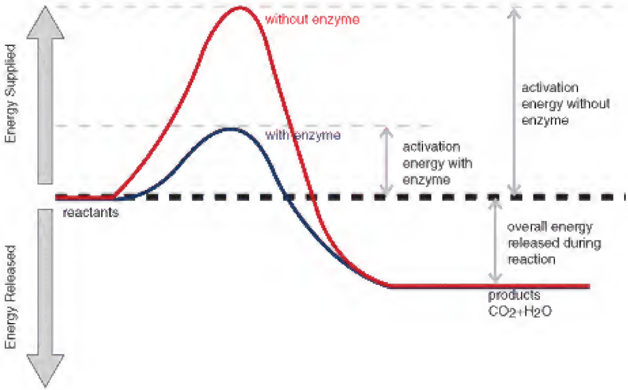

Figure 2.18: The reaction represented by this graph involves the reactants glucose ($C_6H_{12}O_6$) and oxygen (O_2). The products of the reaction are carbon dioxide (CO_2) and water (H_2O). Energy is also released during the reaction. The enzyme speeds up the reaction by lowering the activation energy needed for the reaction to start. Compare the activation energy with and without the enzyme. (24)

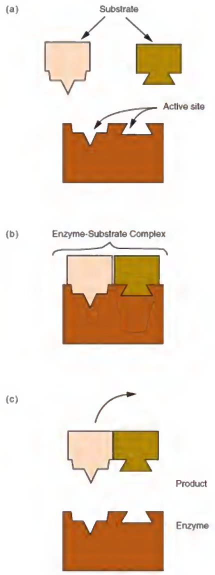

Figure 2.19: This enzyme molecule binds reactant molecules—called substrate—at its active site, forming an enzyme-substrate complex. This brings the reactants together and positions them correctly so the reaction can occur. After the reaction, the products are released from the enzyme's active site. This frees up the enzyme so it can catalyze additional reactions. (11)

Systems chapter). These enzymes would not work optimally at other pHs. Trypsin is another enzyme in the digestive system which break protein chains in the food into smaller parts. Trypsin works in the small intestine, which is not an acidic environment. Trypsin's optimum pH is about 8.

- Biochemical reactions are optimal at physiological temperatures. For example, most biochemical reactions work best at the normal body temperature of 98.6°F. Many enzymes lose function at lower and higher temperatures. At higher temperatures, an enzyme's shape deteriorates and only when the temperature comes back to normal does the enzyme regain its shape and normal activity.

Lesson Summary

- Elements are substances that cannot be broken down into simpler substances with different properties.
- Elements have been organized by their properties to form the periodic table.
- Two or more atoms can combine to form a molecule.
- Molecules consisting of more than one element are called compounds.
- Reactants can combine through chemical reactions to form products.
- Enzymes can speed up a chemical reaction.
- Living things are made of just four classes of macromolecules: proteins, carbohydrates, lipids, and nucleic acids.

Review Questions

1. What is density?
2. What are the 4 main classes of organic compounds?
3. Would water, with the symbol H_2O, be considered an element or a compound?
4. How many types of atoms make up gold?
5. Why do you need fats in your diet?
6. Sugar is what kind of organic compound?
7. What is an atom?
8. What monomers make up proteins?
9. Name a few examples of proteins.
10. Name a few examples of lipids in organisms.
11. What are two nucleic acids?

Further Reading / Supplemental Links

- http://ghr.nlm.nih.gov/handbook/howgeneswork/protein
- http://ghr.nlm.nih.gov/handbook/basics/dna

- http://publications.nigms.nih.gov/thenewgenetics/chapter1.html

Vocabulary

amino acids Monomers that combine to make protein chains.

atom The simplest and smallest particle of matter that still retains the physical and chemical properties of the element; the building block of all matter.

ATP Adenosine triphosphate, the energy "currency" of the cell.

carbohydrates Class of organic compound that includes sugar, starch, cellulose and chitin.

electron A negatively charged particle in the atom, found outside of the nucleus.

element A substance that cannot break down into a simpler substance with different properties.

enzyme Protein that speeds up a chemical reaction by binding to the reactants (substrates).

functional groups Groups of atoms that give a compound its unique chemical properties.

lipids Class of organic compound that includes fats, oils, waxes and phospholipids.

matter Anything that takes up space and has mass.

neutrons The non-charged particle of the atom; located in nucleus of the atom.

nucleic acid Class of organic compound that includes DNA and RNA.

organic compounds Compounds made up of a carbon backbone and associated with living things.

phospholipids Lipid molecule that makes up cell membranes.

product The end result formed from a chemical reaction.

protein Class of organic compound consisting of a chain of amino acids; includes enzymes and antibodies.

Proton The positively charged particle of the atom; located in nucleus of the atom.

Reactants The raw ingredients in a chemical reaction.

Waxes A water-proof lipid.

Points to Consider

- Do you expect the genetic information in the DNA of a cow to be the same or different from that in a crow?
- If we are all composed of the same chemicals, how do all organisms look so different?
- What characteristics would you use to distinguish and classify living things?

2.3 Lesson 2.3: Classification of Living Things

Lesson Objectives

- Explain what makes up a scientific name.
- Explain what defines a species.
- List the information scientists use to classify organisms.
- List the three domains of life and the chief characteristics of each.

Check Your Understanding

- What are the basic characteristics of life?
- What are the four main classes of organic molecules that are building blocks of life?

Introduction

When you see an organism that you've never seen before, you probably automatically classify it into a specific group. If it's green and leafy, you would probably call it a plant. If it's long and slithers, you would probably classify it as a snake. How do you make such assignments? You look at the physical features of the organism and think about what it has in common with other organisms. Scientists do the same thing when they classify living things. But scientists classify organisms not only by their physical features, but also by their evolutionary

history and relatedness. Lions and tigers look like each other more than they look like bears. But it's not just appearance. The two cats are actually more closely related to each other than to bears. How related organisms are is an important basis for classifying them.

Classifying Organisms

People have been concerned with classifying organisms back to the time of the Greeks and Romans. The Greek philosopher Aristotle developed a classification system that divided living things into several groups that we still use today, including mammals, insects, and reptiles. Carl Linnaeus (1707-1778) (**Figure** 2.20) built on Aristotle's work to produce his own extensive classification system and invented the way we name organisms by their genus and species. For example, a coyote's species name is *Canis latrans.* "Latrans" is the **species** and "canis" is the **genus**, a larger group that includes dogs, wolves, and other dog-like animals. Linnaeus is considered the inventor of modern **taxonomy,** the science of naming and grouping organisms. He was especially interested in plants, and he used differences in flowers to classify each plant into groups. Modern taxonomists have reordered many groups of organisms since Linnaeus. The main categories biologists use are listed here from the most specific to the broadest category (**Figure** 2.21). In other words, there are many species in each genus, many genera (plural for "genus") in each family, and so on. The broadest and most inclusive category is the domain. It is currently believed that there are three domains and six kingdoms. We will discuss these groups more later.

But how do taxonomists decide what domain or family an organism belongs to? Like Linnaeus, they still look at the physical features of the organisms and group organisms that look similar together (**Figure** 2.22). But taxonomists also try to piece together evolutionary relationships when assigning organisms to a specific group. By looking at **fossils,** ancient remains of living things, they can tell if organisms share a recent common ancestor–sort of like a "grandparent" species. A common ancestor is an ancestor shared by two groups of organisms. For example lions and tigers share a common ancestor; both species are descended from an ancient cat. If two species share a recent common ancestor, it means they are closely related and they will be placed in the same group.

Another way to determine evolutionary relationships is by looking for similarities or differences in organisms' **DNA**. The number of differences in two organisms' DNA can show how closely related the two organisms are. You might expect, for example, that human DNA is more similar to chimpanzee DNA than to bacterial DNA. (And it is.) How biologists determine evolutionary history will be discussed in more detail in the *Evolution* chapter.

Naming Organisms

Carl Linnaeus recognized a need for a system of names for each species. If we just used common names, we would have many different names in many different languages for the

Figure 2.20: In the 18th century, Carl Linnaeus invented the two-name system of naming organisms (genus and species) and introduced the most complete classification system then known. (8)

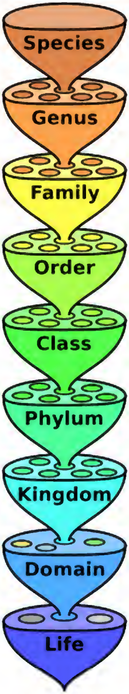

Figure 2.21: This diagram illustrates the classification categories for organisms, with the broadest category (Life) at the bottom, and the most specific category (Species) at the top. (10)

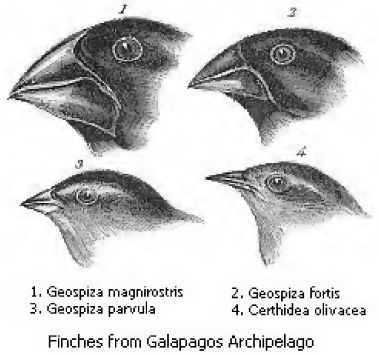

Figure 2.22: Darwin suggested that these Galapagos Island finches share a common ancestor and evolved different beaks because they were eating different foods. Modern research confirms this hypothesis. (23)

same species. To solve this problem, Linnaeus developed **binomial nomenclature,** a way to give a scientific name to every organism. Each species receives a two-part name in which the first word is the genus (a group of species) and the second word refers to one species in that genus. For example, the red maple, *Acer rubra,* and the sugar maple, *Acer saccharum,* are both in the same genus (**Figures** 2.23, 2.24 and 2.25). Notice that the genus is capitalized and the species is not, and that the whole scientific name is in italics. The names are nearly always in Latin, the universal language of scholars throughout European history. Sometimes, biologists use Greek or other words. For example, *Microtus pennsylvanicus* is a species of mouse in Pennsylvania and nearby states.

Figure 2.23: (5)

Figure 2.24: (7)

Even though naming species is straightforward, deciding if two organisms are the same species can sometimes be difficult. Linnaeus defined each species by the distinctive physical characteristics shared by these organisms. But two members of the same species may look quite different. For example, people from different parts of the world sometimes look very different, but we are all the same species (**Figure** 2.26).

So how is a species defined? A **species** is group of individuals that can interbreed with one another and produce fertile offspring; a species does not interbreed with other groups. By this definition, two species of animals or plants that do not interbreed are not the same

Figure 2.25: These leaves in the top and middle photographs are from two different species trees in the Acer, or maple, genus. One of the characteristics of the maple genus is winged seeds (bottom). (28)

species. For example, tigers and lions can mate in zoos and produce kittens that are half tiger and half lion. But we still consider tigers and lions separate species. The two cats look and behave differently and are not known to interbreed in the wild, even though they can. Groups of lions and tigers do not interbreed.

Domains of Life

All life can be divided into 3 domains: Bacteria, Archaea, and Eukarya (**Figures** 2.27, 2.28 and 2.29). This is the largest and least specific classification, so the organisms might not look much alike, but they do have some very important traits in common. For example, you might be surprised that mushrooms, plants, and people are all in the same domain. But when you look at the cells of mushrooms, plants, and people, you will see that they do have some similar features. They are all eukaryotic organisms, or in the domain Eukarya. The other two domains are composed of prokaryotic organisms. Prokaryotic and eukaryotic cells will be discussed in the chapter titled *Cells and Their Functions*.

All the cells in the domain **Eukarya** keep their DNA inside a membrane, a structure called the nucleus. The cells of other domains have DNA, but it is not inside a nucleus. The domain Eukarya is made up of four diverse kingdoms: plants, fungi, animals, and protists.

Plants, such as trees and grasses, survive by capturing energy from the sun, a process called photosynthesis. Animals survive by eating other organisms or the remains of other organisms. Animals range from tiny worms to insects, dogs, and the largest dinosaurs and whales. Fungi, such as mushrooms and molds, also survive by eating other organisms or the remains of other organisms. The last group listed here are the **protists**. Protists are not all descended from a single common ancestor in the way that plants, animals, and fungi are. Protists are a sort of miscellaneous group; they are all the organisms that are not something else. Protists are a diverse group of organisms that include many kinds of microscopic one-celled organisms,

Figure 2.26: These children are all members of the same species, *Homo sapiens*. (15)

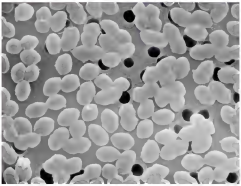

Figure 2.27: The "Group D" Streptococcus organism is in the domain *Bacteria*, one of the three domains of life. (2)

Figure 2.28: The Halobacterium is in the domain *Archaea*, one of the three domains of life. (1)

Figure 2.29: The Western Gray Squirrel is in the domain *Eukarya*, one of the three domains of life. (19)

such as algae and plankton, but also giant seaweeds that can grow to be 200 feet long (an alga protist is shown in **Figure** 2.30). Plants, animals, fungi, and protists might seem very different, but remember that if you look through a microscope, you would find cells with a membrane-bound nucleus in all them.

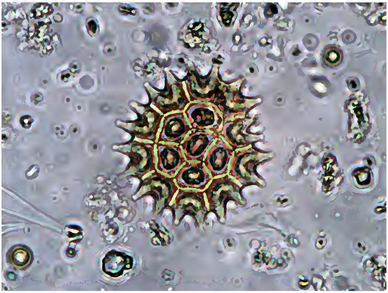

Figure 2.30: This microscopic alga is a protist in the domain Eukarya. (21)

The cells of the two other domains - the **Archaea** and the **Bacteria** - do not have a nucleus. All the cells in both domains are tiny, microscopic one-celled organisms that can reproduce without sex by dividing in two. The difference between the archaea and the bacteria is in their cell walls. Also, archaea often live in extreme environments like hot springs, geysers, and salt flats, while bacteria are abundant and live almost everywhere. A teaspoon of soil can contain 100 million to a billion individual bacteria. Bacteria obtain energy in lots of different ways. Some infect plants and animals and cause disease. Others break down dead organisms. The **cyanobacteria** photosynthesize, like plants. In fact, the ancestors of today's cyanobacteria invented photosynthesis more than two billion years ago.

Table 2.2: **Three domains of life: Bacteria, Archaea, and Eukarya**

	Archaea	Bacteria	Eukarya
Multicelluar	No	No	Yes
Cell Wall	Yes, without peptidoglycan	Yes, with peptidoglycan	Varies. Plants and fungi have a cell wall; animals do not.
Nucleus (DNA inside a membrane)	No	No	Yes

Table 2.2: (continued)

	Archaea	Bacteria	Eukarya
Organelles inside a membrane	No	No	Yes

Viruses

We have all heard of viruses. The flu and many other diseases are caused by viruses. But what is a virus? Based on the material presented in this chapter, are viruses living? No.

A virus is essentially nucleic acid surrounded by protein (**Figure** 2.31). It is not made of a cell; it does not metabolize, it does not maintain homeostasis. Viruses need to infect a host cell to reproduce; they cannot reproduce on their own. However, viruses do evolve. So a virus is very different than any of the organisms that fall into the three domains of life.

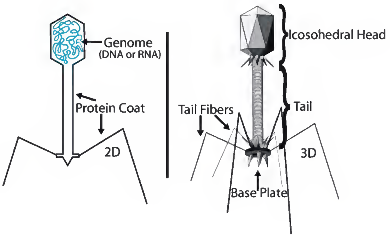

Figure 2.31: These "moon lander" shaped complex virus infects *Escherichia coli* bacteria. (20)

Lesson Summary

- Scientists have defined several major categories for classifying organisms: domain, kingdom, phylum, class, order, family, genus, and species.
- The scientific name of an organism consists of its genus and species.
- Scientists classify organisms according to their evolutionary histories and how related they are to one another - by looking at their physical features, the fossil record, and DNA sequences.
- All life can be classified into three domains: Bacteria, Archaea, and Eukarya.

Review Questions

1. Who designed modern classification and invented the two-part species name?
2. In what domain are humans?
3. *Quercus rubra* is the scientific name for the red oak tree. What is the red oak's genus?
4. In what domain are mushrooms?
5. Is it possible for organisms in two different classes to be in the same genus?
6. How are organisms given a scientific name?
7. Define a species.
8. What kingdoms make up the domain Eukarya?
9. What is the name for the scientific study of naming and classifying organisms?
10. What information do scientists use to classify organisms?
11. If molecular data suggests that two organisms have very similar DNA, what does that say about their evolutionary relatedness?
12. Can two different species ever share the same scientific name?
13. If two organisms are in the same genus, would you expect them to look much alike?

Further Reading / Supplemental Links

- http://www.ucmp.berkeley.edu/history/linnaeus.html
- http://www.physicalgeography.net/fundamentals/9b.html
- http://www.pbs.org/wgbh/nova/orchid/classifying.html

Vocabulary

archaea Microscopic one-celled organisms with no nucleus that tend to live in extreme environments.

bacteria Microscopic one-celled organisms with no nucleus that live everywhere.

binomial nomenclature The system for naming species in which the first word is the genus and the second word is the species.

cyanobacteria Photosynthetic bacteria.

DNA Deoxyribonucleic acid; Nucleic acid molecule that stores the genetic information.

Eukarya Domain in which cells have a nucleus that includes plants, animals, fungi, and protists.

fossils Ancient remains of living things; includes bone, teeth, and impressions.

nucleus Tiny structure inside of some cells that walls off the DNA from the rest of the cell; DNA wrapped inside a membrane.

species Group of organisms that can mate with one another to produce fertile offspring but do not mate with other such groups.

taxonomy The science of naming and classifying organisms.

Points to Consider

- This lesson introduced the diversity of life on Earth. Do you think it is possible for cells from different organisms to be similar even though the organisms look different?
- Do you think human cells are different from bacterial cells?
- Do you think it is possible for a single cell to be a living organism?

Image Sources

(1) CDC. *Archaea*. Public Domain.

(2) Centers for Disease Control and Prevention, United States Department of Health and Human Services. *Bacteria*. Public Domain.

(3) *DNA (nucleic acid)*. Public Domain.

(4) *a molecule of glucose (a carbohydrate)*. Public Domain.

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Chapter 3

Cells and Their Structures

3.1 Lesson 3.1: Introduction to Cells

Lesson Objectives

- Explain how cells are observed.
- Recall the cell theory.
- Explain the levels of organization in an organism.

Check Your Understanding

- What are the main characteristics of living things?
- Name the four main classes of organic molecules that are building blocks of life.

Introduction

How do lipids, carbohydrates, proteins, and nucleic acids come together to form a living organism? By forming a cell. These organic compounds are the raw materials needed for life, and a **cell** is the smallest unit of an organism that is still considered living. Cells are the basic units that make up every type of organism. Some organisms, like bacteria, consist of only one cell. Other organisms, like humans, consist of trillions of specialized cells working together. Even if organisms look very different from each other, if you look close enough you'll see that their cells have much in common. (Use of a microscope in **Figure** 3.1 helps to illustrate this.)

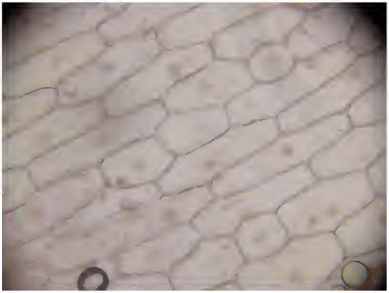

Figure 3.1: The outline of onion cells are visible under a light microscope. (9)

Observing Cells

Most cells are so tiny that you can't see them without the help of a microscope. The microscopes that students typically use at school are light microscopes. Robert Hooke created a primitive light microscope in 1665 and observed cells for the very first time. Although the light microscope opened our eyes to the existence of cells, they are not useful for looking at the tiniest components of cells. Many structures in the cell are too small to see with a light microscope.

When scientists developed more powerful microscopes in the 1950s, the field of cell biology grew rapidly. A light microscope passes a light beam through a specimen, but the more powerful **electron microscope** passes a beam of electrons through the specimen, allowing a much closer look at the cell (**Figure** 3.2).

Transmission electron microscopes (TEM), which pass an electron beam through something, are used to look at a very thin section of an organism and allow us to study the internal structure of cells. **Scanning electron microscopes** (SEM), which pass a beam of electrons across the surface of something, show the details of the shapes of surfaces, giving a 3D image.

Electron microscopes showed many small structures in the cell that had been previously invisible with light microscopes. One drawback to using an electron microscope is that it only images dead cells. A light microscope can be used to study living cells.

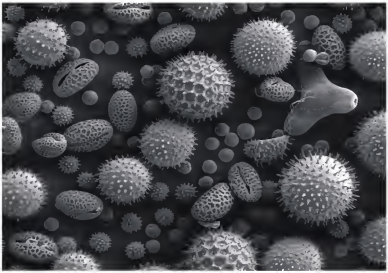

Figure 3.2: An electron microscope allows scientists to see much more detail than a light microscope, as with this sample of pollen. But a light microscope allows scientists to study living cells. (8)

Cell Theory

In 1858, after microscopes had become much more sophisticated than Hooke's first microscope, Rudolf Virchow proposed that cells only came from other cells. For example, bacteria are composed of only one cell (**Figure** 3.3) and divide in half to replicate themselves. In the same way, your body makes new cells by the division of cells you already have. In all cases, cells only come from pre-existing cells.

This concept is central to the cell theory. **The cell theory** states that:

1. All organisms are composed of cells.
2. Cells are alive and the basic living units of organization in all organisms.
3. All cells come from other cells.

As with other scientific theories, the cell theory has been supported by thousands of experiments. And, since Virchow introduced the cell theory, no evidence has ever contradicted it.

Levels of Organization

Although cells share many of the same features and structures, as we will discuss in the next section, they also can be quite different. Each cell in your body is specialized for a specific task. For example:

Figure 3.3: Bacteria (pink) are an example of an organism consisting of only one cell. (4)

- Red blood cells (**Figure** 3.4) are shaped with a pocket to increase their surface area for absorbing and releasing oxygen .
- Nerve cells, which can quickly transmit the sensation of touching a hot stove to your brain, are elongated and stringy to allow them to form a complex network with other nerve cells (**Figure** 3.5) .
- Skin cells (**Figure** 3.6) are flat and fit tightly together.

As you can see, cells are shaped in ways that help them do their jobs. Multicellular (many-celled) organisms have many types of specialized cells in their bodies.

While cells are the basic units of an organism, groups of specialized cells can be organized into tissues. For example, your liver cells are organized into liver tissue, which is organized into an organ, your liver. Organs are formed from two or more specialized tissues working together for a common function. All organs, from your heart to your liver, are made up of an organized group of tissues.

These organs are part of a larger organization pattern, the organ systems. For example, your brain works together with your spinal cord and other nerves to form the nervous system. This organ system must be organized with other organ systems, such as the circulatory system and the digestive system, for your body to work. Organ systems are coordinated together to form the complete organism. As you can see (**Figure** 3.7), there are many levels of organization in living things.

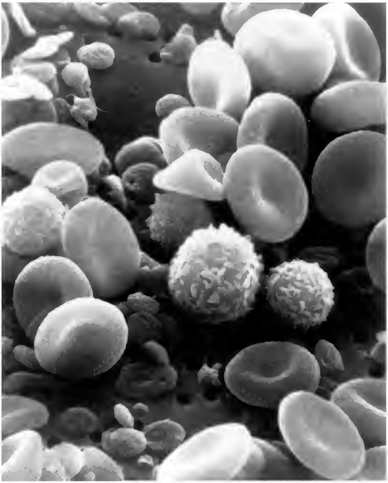

Figure 3.4: Red Blood cells are specialized to carry oxygen in the blood. (12)

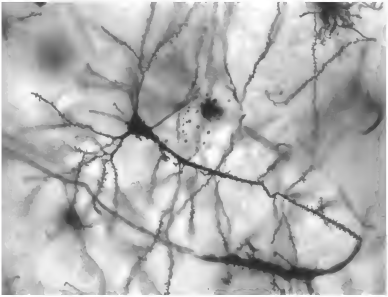

Figure 3.5: Neurons are shaped to conduct electrical impulses to many other nerve cells. (2)

Figure 3.6: These epidermal cells make up the “skin” of plants. Note how the cells fit tightly together. (1)

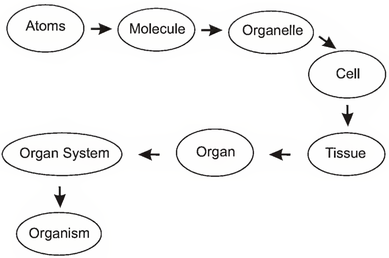

Figure 3.7: Levels of Organization, from the atom to the organism. (3)

Lesson Summary

- Cells were first observed under the light microscope, but today electron microscopes allow scientists to take a closer look at the internal structures of cells
- The Cell Theory says that
  - all organisms are composed of cells;
  - cells are alive and the basic living units of organization in all organisms; and
  - All cells come from other cells.
- Cells are organized into tissues, which are organized into organs, which are organized into organ systems, which are organized to create the whole organism.

Review Questions

1. What type of microscope would you use to study living algae cells?
2. What type of microscope would you use to study the details on the surface of a cell?
3. What type of microscope would be best for studying internal structures of cells?
4. According to the cell theory, can we synthesize a cell in the laboratory from organic molecules?
5. Do all cells work exactly the same?
6. Put the following in the correct order from simplest to most complex: organ, cell, tissue, organ system.

Further Reading / Supplemental Links

- Baeuerle, Patrick A. and Landa, Norbert. *The Cell Works: Microexplorers.* Barron's; 1997, Hauppauge, New York.
- Sneddon, Robert. *The World of the Cell: Life on a Small Scale.* Heinemann Library; 2003, Chicago.
- Wallace, Holly. *Cells and Systems.* Heinemann Library; 2001, Chicago.

Vocabulary

cell The smallest unit of an organism that is still considered living; the basic unit that make up every type of organism.

organ A group of tissues that work together to perform a common function.

organ system A group of organs that work together to perform a common function.

scanning electron microscope (SEM) Microscope that scans the surface of a tissue or cell, showing a 3D image.

tissue A group of specialized cells that function together.

transmission electron microscope (TEM) Microscope used to look at a very thin section of an organism and allow us to study the internal structure of cells.

Points to Consider

- Do you think there would be a significant difference between bacteria cells and your brain cells? What might they be?
- Do you think a bacteria cell and brain cell have some things in common? What might they be?
- Do you think cells are organized? What would be the benefit of organization?

3.2 Lesson 3.2: Cell Structures

Lesson Objectives

- Compare prokaryotic and eukaryotic cells.

- List the organelles of the cell and their functions.
- Discuss the structure and function of the cell membrane and cytosol.
- Describe the structure and function of the nucleus.
- Distinguish between plant and animal cells.

Check Your Understanding

- What is a cell?
- How do we visualize cells?

Introduction

Understanding the structure and function of cells is essential to understanding how living organisms work. Cell biology is central to all other fields of biology, including medicine. Many human diseases and disorders are caused by the malfunction of people's cells. Furthermore, toxins in the environment often act on specific cellular processes. The healthy functioning of the body and its organs is dependent on its smallest unit - the cell.

To better understand the biology of the cell, you will first learn to distinguish the two basic categories of all cells: prokaryotic and eukaryotic cells. You will also learn what makes a cell specialized; there are major differences between a "simple" cell, like a bacteria, and a "complex" cell, like a cell in your brain. To understand these differences, you need to first understand the basic components of the cell, which include the:

- Cell membrane
- Nucleus and chromosomes
- Other organelles

Prokaryotic and Eukaryotic Cells

There are two basic types of cells, **prokaryotic cells** (**Figure** 3.8), which include bacteria and archaea, and **eukaryotic cells** (**Figure** 3.9), which include all other cells. Prokaryotic cells are much smaller and simpler than eukaryotic cells; eukaryotic cells can be considered to be "specialized." Prokaryotic cells are surrounded by a **cell wall** that supports and protects the cell. In prokaryotic cells the DNA, the genetic material, forms a single large circle that coils up on itself. Prokaryotic cells also can contain extra small circles of DNA, known as **plasmids**. The two types of organisms consisting of prokaryotic cells belong to the domain Bacteria and the domain Archaea. These two domains were discussed in the *Introduction to Living Things* chapter.

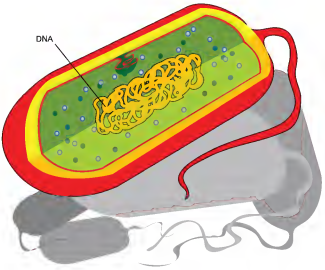

Figure 3.8: Prokaryotes do not have a nucleus. Instead, their genetic material is a simple loop of DNA. (6)

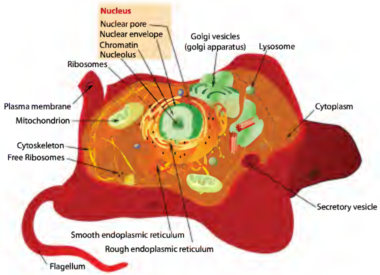

Figure 3.9: Eukaryotic cells contain a nucleus (where the DNA "lives," and surrounded by a membrane) and various other special compartments surrounded by membranes, called "organelles." For example, notice in this image the mitochondria, lysosomes, and peroxisomes. (7)

Table 3.1: **Comparison of Prokaryotic and Eukaryotic Cells**

Feature	Prokaryotic cells	Eukaryotic cells
DNA	Single "naked" circle; plasmids	In membrane-enclosed nucleus
Membrane-enclosed organelles	No	Yes
Examples	Bacteria	Plants, animals, fungi

The main difference between eukaryotic and prokaryotic cells is that eukaryotic cells store their DNA in a membrane-enclosed **nucleus**. The presence of a nucleus is the primary distinguishing feature of a eukaryotic cell. In addition to the nucleus, eukaryotic cells have other subcompartments, small membrane-enclosed structures called **organelles**. Membrane-enclosed organelles and a nucleus are absent in prokaryotic cells. Eukaryotic cells include the cells of fungi, animals, protists, and plants.

The Plasma Membrane and Cytosol

Both eukaryotic and prokaryotic cells have a plasma membrane. The **plasma membrane** is a double layer of specialized lipids, known as phospholipids, along with many special proteins. The function of the plasma membrane, also known as the "cell membrane," is to control what goes in and out of the cell.

Some molecules can go through the cell membrane in and out of the cell and some can't, so biologists say the membrane is **semipermeable**. It is almost as if the membrane chooses what enters and leaves the cell.

The cell membrane gives the cell an inside that is separate from the outside world. Without a cell membrane, the parts of a cell would just float away. A cell needs a boundary even more than we need our skin. Without a cell membrane, a cell would be unable to maintain a stable internal environment separate from the external environment, what we call homeostasis. You can learn more about cell membranes in the *Cell Functions* chapter.

Eukaryotic and prokaryotic cells also share an internal fluid-like substance called the **cytosol**. The cytosol is composed of water and other molecules, including enzymes that speed up the cell's chemical reactions. Everything in the cell - the nucleus and the organelles - sit in the cytosol. The term **cytoplasm** refers to the cytosol and all the organelles, but not the nucleus.

Table 3.2: **Some Eukaryotic Organelles**

Organelle	Function
Ribosomes	Involved in making proteins
Golgi apparatus	Packages proteins and some polysaccharides
Mitochondria	Makes ATP
Smooth ER	Makes lipids
Chloroplast	Makes sugar (photosynthesis)
Lysosomes	Digests macromolecules

The Nucleus and Chromosomes

The nucleus, which is found exclusively in eukaryotic cells, is a membrane-enclosed structure that contains most of the genetic material of the cell (**Figure** 3.10). Like a library, it holds vital information, mainly detailed instructions for building proteins. The **nuclear envelope**, a double membrane that surrounds the nucleus, controls which molecules go in and out of the nucleus.

Inside the nucleus are the chromosomes, the DNA all wrapped in special proteins. The genetic information on the chromosomes is stored made it available to the cell when necessary and also duplicated when it is time to pass the genetic information on when a cell divides. All the cells of a species carry the same number of chromosomes. For example, human cells each have 23 pairs of chromosomes. Each chromosome in turn carries hundreds or thousands of genes that encode proteins that help determine traits as varied as tooth shape, hair color, or kidney function.

The Cell Factory

Just as a factory is made up of many people, machines, and specific areas, each part of the whole playing a different role, a cell is also made up of different parts, each with a special role. For example, the nucleus of a cell is like a safe containing the factory's trade secrets, including how to build thousands of proteins, how much of each one to make, and when. The **mitochondria** are powerhouses that generate the ATP needed to power chemical reactions. Plant cells have special organelles called **chloroplasts** that capture energy from the sun and store it in the chemical bonds of sugar molecules - in the process called photosynthesis (**Figure** 3.11). (The cells of animals and fungi do not photosynthesize and do not have chloroplasts.)

The **vacuoles** are storage centers, and the **lysosomes** are the recycling trucks that carry waste away from the factory. Inside lysosomes are enzymes that break down old molecules into parts that can be recycled into new ones. Eukaryotic cells also contain and internal skeleton called the **cytoskeleton**. Like our bony skeleton, a cell's cytoskeleton gives the cell

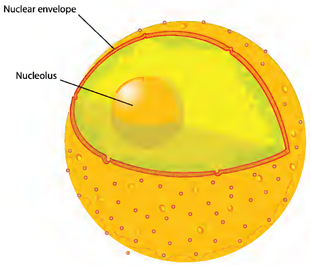

Figure 3.10: In eukaryotic cells, the DNA is kept in a nucleus. The nucleus is surrounded by a double plasma membrane called the **nuclear envelope**. Within the nucleus is the *nucleolus* (smaller yellow ball). (11)

a shape and helps it move parts of the cell.

In both eukaryotes and prokaryotes, **ribosomes** are where proteins are made. Some ribosomes cluster on folded membranes called the endoplasmic reticulum (ER). If the ER is covered with ribosomes, it looks bumpy and is called rough ER. If the ER lacks ribosomes, it is smooth and is called smooth ER. Proteins are made on rough ER and lipids are made on smooth ER.

Another set of folded membranes in cells is the **Golgi apparatus**, which works like a mail room. The Golgi apparatus receives the proteins from the rough ER, puts sugar molecule "shipping addresses" on the proteins, packages them up in vesicles, and then sends them to the right place in the cell.

Plant Cells

Even though plants and animals are both eukaryotes, plant cells differ in some ways from animal cells. First, plant cells are unique in having a large central **vacuole** that holds a mixture of water, nutrients, and wastes. A plant cell's vacuole can make up 90% of the cell's volume. In animal cells, vacuoles are much smaller.

Second, plant cells have a cell wall, which animal cells do not. A **cell wall** gives the plant cell strength, rigidity, and protection. Although bacteria and fungi also have cell

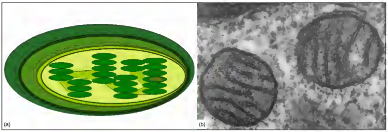

Figure 3.11: Diagram of chloroplast (a) and electron microscope image of two mitochondria (b). Chloroplasts and mitochondria provide energy to cells. If the bar at the bottom of the electron micrograph image is 200 nanometers, what is the diameter of one of the mitochondria? (10)

walls, a plant cell wall is made of a different material. Plant cell walls are made of the polysaccharides cellulose, fungal cell walls are made of chitin, and bacterial cell walls are made of peptidoglycan. This is highlighted in **Figure** 3.12.

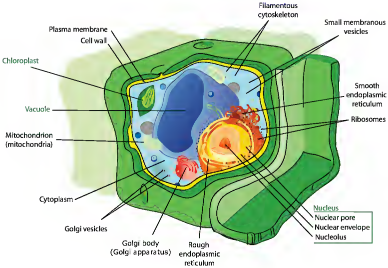

Figure 3.12: A plant cell has several features that make it different from an animal cell, including a cell wall, huge vacuoles, and several kinds of plastids, including chloroplasts (which photosynthesize). (5)

A third difference between plant and animal cells is that plants have several kinds of organelles called **plastids**. There are several kinds of plastids, including **chloroplasts**, needed for photosynthesis; **leucoplasts**, which store starch and oil; and brightly colored **chromoplasts**, which give some flowers and fruits their yellow, orange, or red color. You will learn more about chloroplasts and photosynthesis in the chapter titled *Cell Functions*. Under a microscope one can see plant cells more clearly (**Figure** 3.13).

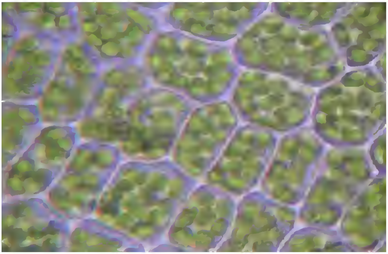

Figure 3.13: In this photo of plant cells taken with a light microscope, you can see a cell wall (purple) around each cell and green chloroplasts. (13)

Lesson Summary

- Prokaryotic cells lack a nucleus; eukaryotic cells have a nucleus.
- Each component of a cell has a specific function.
- Plant cells have unique features including plastids, cell walls, and central vacuoles.

Review Questions

1. What are the two basic types of cells?
2. What are organelles?
3. Discuss the main differences between prokaryotic cells and eukaryotic cells.
4. What is the plasma membrane and what is its role?
5. What organelle is known as the "powerhouse" of the cell?
6. Why does photosynthesis not occur in animal cells?
7. What are the main differences between a plant cell and an animal cell?

Further Reading / Supplemental Links

- Baeuerle, Patrick A. and Landa, Norbert. *The Cell Works: Microexplorers.* Barron's; 1997, Hauppauge, New York.
- Sneddon, Robert. *The World of the Cell: Life on a Small Scale.* Heinemann Library; 2003, Chicago.
- Wallace, Holly. *Cells and Systems.* Heinemann Library; 2001, Chicago.

Vocabulary

cell The smallest unit of an organism that is still considered living; the basic unit that make up every type of organism.

cell wall Provides strength and protection for the cell; found around plant, fungal, and bacterial cells.

central vacuole Large organelle containing water, nutrients, and wastes that can take up to 90% of a plant cell's volume.

chloroplast Green organelle that captures solar energy and stores the energy in sugars through the process of photosynthesis; chloroplasts are found only in cells that perform photosynthesis.

chromosome The cell structure in eukaryotic cells containing the genes; made of DNA and protein. Human cells have 23 pairs of chromosomes.

cytoplasm All the contents of the cell besides the nucleus, including the cytosol and the organelles.

cytoskeleton The internal scaffolding of the cell; maintains the cell shape and aids in moving the parts of the cell.

cytosol A fluid-like substance inside the cell; organelles are embedded in the cytosol.

endoplasmic reticulum (ER) A folded membrane organelle; rough ER modifies proteins and smooth ER makes lipids.

eukaryotic cell Cell belonging to the domain Eukarya (fungi, animals, protists, and plants); has a membrane-enclosed nucleus and various organelles.

golgi apparatus The organelle where proteins are modified, labeled, packaged into vesicles, and shipped.

homeostasis The ability to maintain a stable internal environment separate from the external environment.

lysosome Organelle which contains enzymes that break down unneeded materials.

mitochondria The organelle in all eukaryotic cells that makes adenosine triphosphate (ATP), the "energy currency" of cells.

nuclear envelope A double membrane that surrounds the nucleus; helps regulate the passage of molecules in and out of the nucleus.

nucleus Membrane enclosed organelle in eukaryotic cells that contains the DNA; primary distinguishing feature between a eukaryotic and prokaryotic cell; the information center, containing instructions for making all the proteins in a cell, as well as how much of each one.

organelle Small structure wrapped in a membrane found only in eukaryotic cells; mitochondria, plastids, and vacuoles, for example. A ribosome is not technically an organelle, because it is not enclosed in a membrane.

plasma membrane Surrounds the cell; made of a double layer of specialized lipids, known as phospholipids, with embedded proteins; regulates the movement of substances into and out of the cell; also called the cell membrane.

plasmid Small circular piece of DNA; found in prokaryotic cells.

prokaryotic cell Cell with no nucleus or other membrane-enclosed organelles; bacteria and archaea.

ribosome The cell structure on which proteins are made; not surrounded by a membrane; found in both prokaryotic and eukaryotic cells.

rough endoplasmic reticulum The part of the ER with ribosomes attached; proteins can be modified in the rough ER before they are packed into vesicles for transport to the golgi apparatus.

semi-permeable allowing only certain materials to pass through; characteristic of the cell membrane.

smooth endoplasmic reticulum Part of the ER that does not have ribosomes attached; where lipids are synthesized.

vesicle Small membrane-enclosed sac; transports proteins around a cell or out of a cell.

Points to Consider

- Think about what molecules would need to be transported into cells.
- Discuss why it would be important for some molecules to be kept out of a cell.

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Chapter 4

Cell Functions

4.1 Lesson 4.1: Transport

Lesson Objectives

- Describe several methods of transporting molecules and ions into and out of the cell.
- Distinguish between active and passive transport.
- Explain how diffusion and osmosis work.

Check Your Understanding

- What structure surrounds the cell?
- What is the primary component of the cell membrane?
- What does homeostasis mean?

Introduction

All organisms and their cells need to maintain homeostasis. But how can a cell keep a stable internal environment when the environment around the cell is constantly changing? Obviously, the cell needs to separate itself from the external environment. This job is accomplished by the cell membrane. The cell membrane is **selectively permeable,** or "semipermeable," which means that only some molecules can get through the membrane. If the cell membrane was completely permeable, the inside of the cell would be about the same as the outside and the cell could not achieve homeostasis.

How does the cell maintain this selective permeability? How does the cell control what molecules enter and leave the cell? The ways that cells control what passes through the cell

membrane will be the focus of this lesson.

What is Transport?

The selectively permeable nature of the plasma membrane is due in part to the chemical composition of the membrane. Recall that the membrane is a double layer of phospholipids (a "bilayer") embedded with proteins (**Figure** 4.1). A single phospholipid molecule has a hydrophilic, or water-loving, head and hydrophobic, or water-fearing, tail. The hydrophilic heads face the inside and outside of the cell, where water is abundant. The water-fearing, hydrophobic tails face each other in the middle of the membrane. At body temperature, the plasma membrane is fluid and constantly moving, like a soap bubble; it is not a solid structure.

Water and small non-charged molecules such as oxygen and carbon dioxide can pass freely through the membrane by slipping around the phospholipids. But larger molecules and charged molecules cannot pass through the plasma membrane easily. Therefore, special methods are needed for transporting some molecules across the plasma membrane and into or out of the cell.

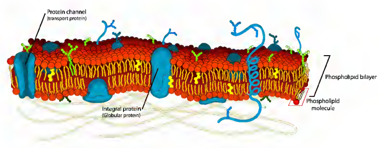

Figure 4.1: The plasma membrane is made up of a phospholipid bilayer with embedded proteins. (9)

Since atoms have an equal number of protons and electrons, they have no net charge. The negative charges of the electrons balance out the positive charges of the protons. Many molecules have an equal number of electrons and protons, so we call them non-polar molecules. However, some atoms can lose or gain electrons easily, giving them a positive or negative charge. These charged particles are called **ions.** If an atom loses an electron, it becomes a positively charged ion, such as the sodium ion Na^+. If an atom gains an electron, it will be a negatively charged ion, such as the chloride ion, Cl^-. Na^+ and Cl^- readily form NaCl, or common table salt. Since Na^+ and Cl^- are charged, they are unable to pass freely through the plasma membrane.

Passive Transport

Small molecules can pass through the plasma membrane through a process called diffusion. **Diffusion** is the movement of molecules from an area where there is a higher concentration (larger amount) of the substance to an area where there is a lower concentration (lower amount) of the substance. The amount of a substance in relation to the volume, is called **concentration**. Diffusion requires no energy input from the cell (**Figure** 4.2). Diffusion occurs by the random movement of molecules; molecules move in both directions (into and out of the cell), but there is a greater movement from an area of higher concentration towards an area of lower concentration. The movement of the substance from a greater concentration to a lesser concentration is referred to as moving down the concentration gradient. For example, oxygen diffuses out of the air sacs in your lungs into your bloodstream because oxygen is more concentrated in your lungs than in your blood. Oxygen moves down the concentration gradient from your lungs into your bloodstream

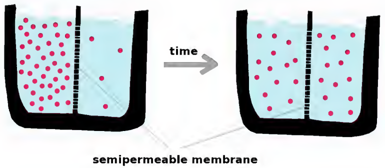

Figure 4.2: Diffusion across a membrane does not require an input of energy. (2)

The diffusion of water across a membrane due to concentration differences is called **osmosis.** If a cell is placed in a **hypotonic solution,** meaning the solution has a lower concentration of dissolved material than what is inside the cell, water will move into the cell. This causes the cell to swell, and it may even burst. Organisms that live in fresh water, which is a hypotonic solution, have to prevent too much water from coming into their cells. Freshwater fish excrete a large volume of dilute urine to rid their bodies of excess water.

If a cell is placed in a **hypertonic solution,** meaning there is more dissolved material in the outside environment than in the cell, water will leave the cell. That can cause a cell to shrink and shrivel. Marine animals live in salt water, which is a hypertonic environment; there is more salt in the water than in their cells. To prevent losing too much water from their bodies, these animals intake large quantities of salt water and secrete salt by active transport, which will be discussed later in this lesson.

To keep cells intact, they need to be placed in an **isotonic solution,** a solution in which the amount of dissolved material is equal both inside and outside the cell. Therefore, there is no net movement of water into or out of the cell. Water still flows in both directions, but an

equal amount enters and leaves the cell. In the medical setting, red blood cells can be kept intact in a solution that is isotonic to the blood cells. If the blood cells were put in pure water, the solution would be hypotonic to the blood cells, so the blood cells would swell and burst. This is represented in the **Figure** 4.3.

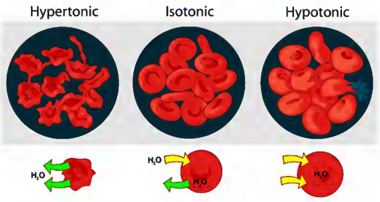

Figure 4.3: Osmosis causes these red blood cells to change shape by losing or gaining water. (1)

Sometimes diffusion across the membrane is slow or even impossible for some charged or large molecules. These molecules need the help of special helper proteins that are located in the plasma membrane. **Ion channel proteins** move ions across the plasma membrane. Other molecules, such as glucose, move across the cell membrane by **facilitated diffusion,** in which a carrier protein physically moves the molecule across the membrane (**Figure** 4.4). Both channel proteins and carrier proteins are specific for the molecule transported. Movement by ion channel proteins and facilitated diffusion are still considered **passive transport,** meaning they move molecules down the cell's concentration gradient and do not require any energy input.

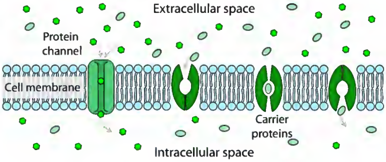

Figure 4.4: Facilitated Diffusion is a type of passive transport where a carrier protein aids in moving the molecule across the membrane. (11)

Active Transport

During active transport, molecules move against the concentration gradient, toward the area of higher concentration. This is the opposite of diffusion. Active transport requires both an input of energy, in the form of ATP, and a carrier protein to move the molecules. These proteins are often called pumps, because, as a water pump uses energy to force water against gravity, proteins involved in active transport use energy to move molecules against their concentration gradient.

There are many examples of why active transport is important in your cells. One example occurs in your nerve cells. In these cells, the **sodium-potassium pump** (**Figure** 4.5) moves sodium outside the cell and potassium into the cell, both against their concentration gradients.

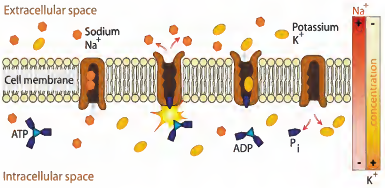

Figure 4.5: The sodium-potassium pump moves sodium ions to the outside of the cell and potassium ions to the inside of the cell. ATP is required for the protein to change shape. As ATP adds a phosphate group to the protein, it leaves behind adenosine diphosphate (ADP). (14)

Transport Through Vesicles

Some large molecules are just too big to move across the membrane, even with the help of a carrier protein. These large molecules must be moved through vesicle formation, a process by which the large molecules are packaged in a small bubble of membrane for transport. This process keeps the large molecules from reacting with the cytoplasm of the cell. Vesicle formation does require an input of energy, however.

There are several kinds of vesicle formation that allow large molecules to move across the plasma membrane. **Exocytosis** moves large molecules outside of the cell. During exocytosis, the vesicle carrying the large molecule fuses with the plasma membrane. The large molecule is then released outside of the cell, and the vesicle is absorbed into the plasma membrane. **Endocytosis** is the process by which cells take in large molecules by vesicle formation. Types

of endocytosis include phagocytosis and pinocytosis. **Phagocytosis** moves large substances, even another cell, into the cell. Phagocytosis occurs frequently in single-celled organisms, such as amoebas. **Pinocytosis** (**Figure** 4.6) involves the movement of liquid or very small particles into the cell. These processes cause some membrane material to be lost as these vesicles bud off and come into the cell. This membrane is replaced by the membrane gained through exocytosis.

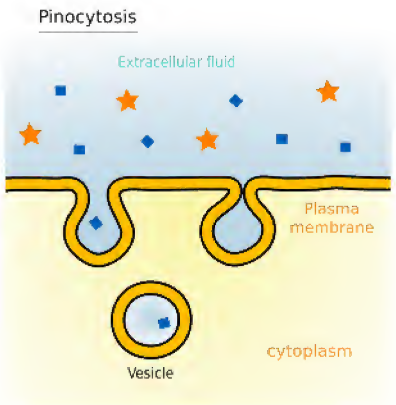

Figure 4.6: During endocytosis, exocytosis and pinocytosis, substances are moved into or out of the cell via vesicle formation. (13)

Lesson Summary

- The plasma membrane is selectively permeable or semi-permeable, meaning that some molecules can move through the membrane easily, while others require specialized transport mechanisms.
- Passive transport methods, including diffusion, ion channels, facilitated diffusion, and osmosis, move molecules in the direction of the lowest concentration of the molecule and do not require energy.

- Active transport methods move molecules in the direction of the higher concentration and require energy and a carrier protein.
- Vesicles can be used to move large molecules, which requires energy input.

Review Questions

1. What happens when a cell is placed in a hypotonic solution?
2. What happens when a cell is placed in a hypertonic solution?
3. What's the main difference between active and passive transport?
4. List an example of active transport.
5. List the types of passive transport.
6. Why is the plasma membrane considered semipermeable?
7. What is the process where a cell engulfs a macromolecule, forming a vesicle?
8. What is diffusion?
9. Explain the results of a sodium-potassium pump working across a membrane.
10. Does facilitated transport move a substance down or up a gradient?

Further Reading / Supplemental Links

- http://www.vivo.colostate.edu/hbooks/cmb/cells/pmemb/passive.html
- http://www.vivo.colostate.edu/hbooks/molecules/sodium_pump.html
- http://www.biologycorner.com/bio1/diffusion.html
- http://www.northland.cc.mn.us/biology/Biology1111/animations/transport1.html
- http://www.brookscole.com/chemistry_d/templates/student_resources/shared_resources/animations/ion_pump/ionpump.html
- http://www.enwikipedia.org/

Vocabulary

active transport Moving a molecule from an area of lower concentration to an area of higher concentration; requires a carrier protein and energy.

concentration The amount of a substance in relation to the volume.

diffusion Movement of molecules from an area of high concentration to an area of low concentration; requires no energy.

endocytosis Movement of substances into the cell by vesicle formation.

exocytosis Movement of substances out of the cell by a vesicle fusing with the plasma membrane.

facilitated diffusion Diffusion in which a carrier protein physically moves the molecule across the membrane; a form of passive transport.

homeostasis Maintaining a stable internal environment despite any external changes.

hypertonic solution Having a higher solute concentration than the cell; cell will lose water by osmosis.

hypotonic solution Having a lower solute concentration than the cell; cell will gain water by osmosis.

ion An atom that carries a negative or positive charge.

ion channel Protein in the plasma membrane that allows ions to pass through.

isotonic solution A solution in which the amount of dissolved material is equal both inside and outside the cell; no net gain or loss of water.

osmosis Diffusion of water across a membrane.

passive transport Movement of molecules from an area of higher concentration to an area of lower concentration; requires no energy.

phagocytosis Movement of large substances, including other cells, into the cell by vesicle formation.

phospolipid A lipid molecule with a hydrophilic head and two hydrophobic tails; makes up the cell membrane.

pinocytosis Movement of macromolecules into the cell by vesicle formation.

selectively permeable Semipermeable; property of allowing only certain molecules to pass through the cell membrane.

sodium-potassium pump Carrier protein that moves sodium ions out of the cell and potassium ions into the cell; works against the concentration gradient and requires energy.

vesicle formation The formation of a small membrane-bound sac that can store and move substances into and out of the cell.

Points to Consider

- The next lesson discusses photosynthesis.
- It is often said that plants make their own food. What do you think this means?
- What substances would need to move into a leaf cell?
- What substances would need to move out of a leaf cell?

4.2 Lesson 4.2: Photosynthesis

Lesson Objectives

- Explain the importance of photosynthesis.
- Write and interpret the chemical equation for photosynthesis.
- Describe what happens during the light reactions and the Calvin Cycle.

Check Your Understanding

- How are plant cells different from animal cells?
- In what organelle does photosynthesis take place?

Introduction

Almost all life on Earth depends on photosynthesis. Recall that photosynthesis is the process by which plants use the sun's energy to make their own "food" from carbon dioxide and water. For example, animals, such as caterpillars, eat plants and therefore rely on the plants to obtain energy. If a bird eats a caterpillar, then the bird is obtaining the energy that the caterpillar gained from the plants. So the bird is indirectly getting energy that began with the "food" formed through photosynthesis. Almost all organisms obtain their energy from photosynthetic organisms, either directly, by eating photosynthetic organisms, or indirectly by eating other organisms that ultimately obtained their energy from photosynthetic organisms. Therefore, the process of photosynthesis is central to sustaining life on Earth.

Overview of Photosynthesis

Photosynthesis is the process that converts the energy of the sun, or solar energy, into carbohydrates, a type of chemical energy. During photosynthesis, carbon dioxide and water combine with solar energy, yielding glucose (the carbohydrate) and oxygen. As mentioned previously, plants can photosynthesize, but plants are not the only organisms with this ability. Algae, which are plant-like protists, and cyanobacteria (certain bacteria which are

also known as blue-green bacteria, or blue-green algae) can also photosynthesize. Algae and cyanobacteria are important in aquatic environments as sources of food for larger organisms.

Photosynthesis mostly takes place in the leaves of a plant. The green pigment in leaves, **chlorophyll,** helps to capture solar energy. And special structures within the leaves provide water and carbon dioxide, which are the raw materials for photosynthesis. The veins within a leaf carry water which originates from the roots, and carbon dioxide enters the leaf from the air through special pores called **stomata** (**Figure** 4.7).

Figure 4.7: Stomata are special pores that allow gasses to enter and exit the leaf. (4)

The water and carbon dioxide are transported within the leaf to the **chloroplast** (**Figure** 4.8), the organelle in which photosynthesis takes place. The chloroplast has two distinct membrane systems; an outer membrane surrounds the chloroplast and an inner membrane system forms flattened sacs called **thylakoids.** As a result, there are two separate spaces within the chloroplast. The interior space that surrounds the thylakoids is filled with a fluid called **stroma.** The inner compartments formed by the thylakoid membranes are called the thylakoid space.

The overall chemical reaction for photosynthesis is 6 molecules of carbon dioxide (CO_2) and 6 molecules of water (H_20), with the addition of solar energy, yields 1 molecule of glucose ($C_6H_{12}O_6$) and 6 molecules of oxygen (O_2). Using chemical symbols the equation is represented as follows:

$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

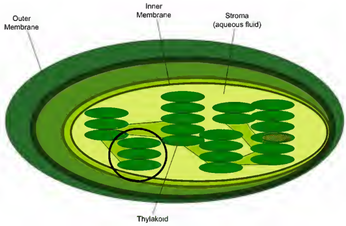

Figure 4.8: The chloroplast is the photosynthesis factory of the plant. (7)

Oxygen: An Essential Byproduct

Oxygen is a byproduct of the process of photosynthesis and is released to the atmosphere through the stomata. Therefore, plants and other photosynthetic organisms play an important ecological role in converting carbon dioxide into oxygen. As you know, animals need oxygen to carry out the energy-producing reactions of their cells. Without photosynthetic organisms, many other organisms would not have enough oxygen in the atmosphere to survive. Oxygen is also used as a reactant in cellular respiration, which is discussed in the next lesson, so essentially, oxygen cycles through the processes of photosynthesis and cellular respiration.

The Light Reactions and the Calvin Cycle

The overall process of photosynthesis does not happen in one step, however. The chemical equation of photosynthesis shows the results of many chemical reactions. The chemical reactions that make up the process of photosynthesis can be divided into two groups: the light reactions (also known as the light-dependent reactions, because these reactions only occur during daylight hours) and the Calvin Cycle, or the light-independent reactions. During the **light reactions**, the energy of sunlight is captured, while during the **Calvin Cycle**, carbon dioxide is converted into glucose, which is a type of sugar. This is summarized in **Figure** 4.9.

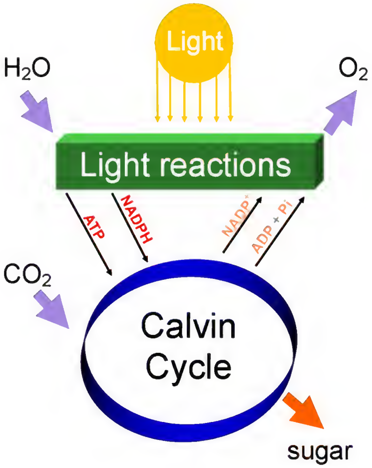

Figure 4.9: This overview of photosynthesis shows that light is captured during the light reactions, resulting in the production of ATP and the electron carrier NADPH. Through the Calvin Cycle, these materials are used to fix carbon dioxide into sugar. Also during the Calvin Cycle, $NADP^+$ and ADP are regenerated. (3)

Stage 1: Capturing Light Energy

In the first step of the light reactions, solar energy is absorbed by the chlorophyll (and accessory pigments) within the chloroplast's thylakoid membranes. This absorbed energy excites electrons in the thylakoid membranes. The electrons are then transferred from the thylakoid membranes by a series of electron carrier molecules. The series of electron carrier molecules that transfers electrons is called the electron transport chain. During this process water molecules in the thylakoid are split to replace the electrons that left the pigment, releasing oxygen and adding hydrogen ions (H^+) to the thylakoid space. As the thylakoid becomes a reservoir for hydrogen ions, a **chemiosmotic gradient** forms as there are more hydrogen ions in the thylakoid than in the stroma. As H^+ ions flows from the high concentration in the thylakoid to the low concentration in the stroma, they provide energy as they pass through an enzyme called ATP synthase. ATP synthase uses the energy of the movement of H^+ ions to make ATP. Meanwhile, highly energized electrons from the electron transport chain combine with the electron carrier $NADP^+$ to become NADPH (**Figure** 4.10). NADPH will carry this energy in the electrons to the next phase of photosynthesis, the Calvin Cycle.

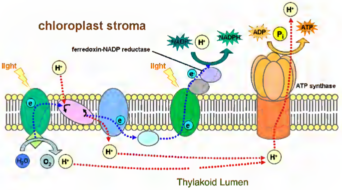

Figure 4.10: The light reactions includes the movement of electrons down the electric transport chain, splitting water and releasing hydrogen ions into the thylakoid space. (5)

Stage 2: Producing Food

During the Calvin Cycle, which occurs in the stroma of the chloroplast, glucose is formed from carbon dioxide and the products of the light reactions. During the first step CO_2 is attached to a 5-carbon molecule (called Ribulose-5-Phosphate, RuBP), forming a 6-carbon molecule. This reaction is catalyzed by an enzyme named RuBisCo, which is the most abundant protein in plants and maybe on Earth! The 6-carbon molecule formed by this reaction immediately splits into two 3-carbon molecules, and the 3-carbon molecule is rearranged to a 3-carbon carbohydrate. The energy and electrons needed for this process are provided by the ATP and

NADPH produced earlier in photosynthesis. The "food" made by photosynthesis is formed from the 3-carbon carbohydrate. Two 3-carbon carbohydrates combine to form glucose, a 6-carbon carbohydrate. Next, the 6-carbon RuBP must be reproduced so the Calvin Cycle can start again (**Figure** 4.11).

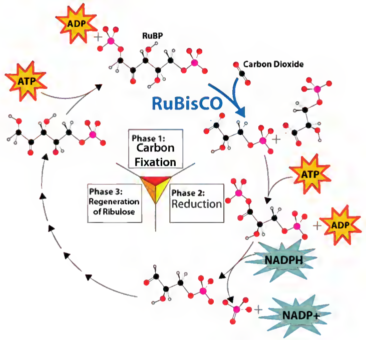

Figure 4.11: The Calvin Cycle begins with carbon fixation, or carbon dioxide attaching to the 5-carbon molecule RuBP, forming a 6-carbon molecule and splitting immediately in to two 3-carbon molecules. This is shown at the top of the figure. This carbon molecule is then reduced to a 3-carbon carbohydrate, shown at the bottom of the figure. The energy and reducing power needed for this process are provided by the ATP and NADPH produced from the light reactions. Next, RuBP must be reproduced so the Calvin Cycle can continue. *The carbons are the small black circles. You can keep track of the number of carbons at each stage by counting these circles.* (10)

The 3-carbon product of the Calvin Cycle can be converted into many types of organic molecules. Glucose, the energy source of plants and animals, is only one possible product of photosynthesis. Glucose is formed by two turns of the Calvin Cycle. Glucose can be formed into long chains as **cellulose**, a structural carbohydrate, or **starch**, a long-term storage carbohydrate. The product of the Calvin Cycle can also be used as the backbone of fatty acids, or amino acids, which make up proteins.

Photosynthesis is crucial to most ecosystems since animals obtain energy by eating other animals, or plants and seeds that contain these organic molecules. In fact, it is the process of photosynthesis that supplies almost all the energy to an ecosystem.

Lesson Summary

- The net reaction for photosynthesis is that carbon dioxide and water, together with energy from the sun, produce glucose and oxygen.
- During the light reactions of photosynthesis, solar energy is converted into the chemical energy of ATP and NADPH.
- During the Calvin Cycle, the chemical energy of ATP and NADPH is used to convert carbon dioxide into glucose.

Review Questions

1. What is the energy-capturing stage of photosynthesis?
2. What are the products of the light reactions?
3. What are the ATP and NADPH from the light reactions used for?
4. Where does the oxygen released by photosynthesis come from?
5. What happens to the glucose produced from photosynthesis?
6. Describe the structures of the chloroplast where photosynthesis takes place.
7. What is the significance of the electron transport chain?
8. What are the reactants required for photosynthesis?
9. What are the products of photosynthesis?

Further Reading / Supplemental Links

- http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookPS.html
- http://photoscience.la.asu.edu/photosyn/education/photointro.html
- http://www.pbs.org/wgbh/nova/methuselah/photosynthesis.html
- http://www.science.smith.edu/departments/Biology/Bio231/ltrxn.html
- http://www.biology4all.com/resources_library/details.asp?ResourceID=43
- http://www.enwikipedia.org/

Vocabulary

ATP synthase An enzyme that uses the energy of the movement of H^+ ions to make ATP.

Calvin Cycle The reactions of photosynthesis in which carbon dioxide is converted into glucose, which is a type of sugar; also known as the light independent reactions.

chlorophyll Green pigment in leaves; helps to capture solar energy.

chloroplast The organelle in which photosynthesis takes place.

cyanobacteria Photosynthetic bacteria; also known as blue-green bacteria, or blue-green algae.

electron transport chain A series of electron carrier molecules that transfers electrons.

light reactions The reactions of photosynthesis that only occur during daylight hours in which the energy of sunlight is captured; also known as the light-dependent reactions.

NADPH A high energy electron carrier produced during the light reactions; carries the energy in the electrons to the Calvin Cycle.

photosynthesis The process by which plants use the sun's energy to make their own "food" from carbon dioxide and water; process that converts the energy of the sun, or solar energy, into carbohydrates, a type of chemical energy.

stomata Special pores in leaves; carbon dioxide enters the leaf and oxygen exits the leaf through these pores.

stroma Fluid in the chloroplast interior space; surrounds the thylakoids.

thylakoid Flattened sacs within the chloroplast; formed by the inner membranes.

Points to Consider

- How is glucose turned into an usable form of energy called ATP?
- How do you gain energy from the food you eat?
- What would provide more energy- a bowl of pasta or a small piece of candy?
- What "waste" gas do you exhale?

4.3 Lesson 4.3: Cellular Respiration

Lesson Objectives

- Write and explain the chemical formula for cellular respiration.
- Explain the two states of cellular respiration.
- Compare photosynthesis with cellular respiration.
- Describe the results of fermentation and understand when fermentation is needed.

Check Your Understanding

- Where does the energy captured at the beginning of photosynthesis originate from?
- What is the form of chemical energy produced by photosynthesis?
- What occurs in oxidation and reduction reactions?

Introduction

How does the food you eat provide energy? When you need a quick boost of energy, you might reach for an apple or a candy bar. Although foods with sugars can give you a quick boost of energy, they cannot be used for energy directly by your cells. Energy is simply stored in these foods. Through the process of **cellular respiration,** the energy in food is converted into energy that can be used by the body's cells. In other words, glucose (and oxygen) is converted into ATP (and carbon dioxide and water). ATP is the molecule that provides energy for your cells to perform work, such as contracting your muscles as you walk down the street or performing active transport. Cellular respiration is simply a process that converts one type of chemical energy, the energy stored in sugar, into another type, ATP.

Overview of Cellular Respiration

Most often, cellular respiration proceeds by breaking down glucose into carbon dioxide and water. As this breakdown of glucose occurs, energy is released. The process of cellular respiration includes the conversion of this energy into ATP. The overall reaction for cellular respiration is as follows:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

Notice that the equation for cellular respiration is the direct opposite of photosynthesis. While water was broken down to form oxygen during photosynthesis, in cellular respiration oxygen is combined with hydrogen to form water. While photosynthesis requires carbon dioxide and releases oxygen, cellular respiration requires oxygen and releases carbon dioxide. This exchange of carbon dioxide and oxygen in all the organisms that use photosynthesis and/or cellular respiration worldwide, helps to keep atmospheric oxygen and carbon dioxide at somewhat stable levels.

Cellular respiration doesn't happen all at once, however. Glucose is broken down slowly so that cells convert as much sugar as possible into the usable form of energy, ATP. Still, some energy is lost in the process in the form of heat. When one molecule of glucose is broken down, it can be converted to a net total of 36 or 38 molecules of ATP. Although the process is not 100% efficient, it is much more efficient than a car engine obtaining energy from gasoline.

Cellular respiration can be divided into three phases.

1. Glycolysis: the breakdown of glucose.
2. The citric acid cycle: the formation of electron carriers.
3. The electron transport chain: the formation of ATP.

In eukaryotic cells, the first phase takes place in the cytoplasm of the cell, while the other phases are carried out in the mitochondria. This organelle is known as the "powerhouse" of the cell because this is the organelle where the ATP that powers the cell is produced.

Glycolysis

The first step of cellular respiration is glycolysis. During **glycolysis,** the 6-carbon glucose is practically "cut in half," broken down into two 3-carbon pyruvate molecules. Glycolysis requires an initial energy-investment step, although in the end, glycolysis produces more energy than was initially invested. Two ATP molecules are used to convert glucose into the two 3-carbon pyruvate molecules. These 3-carbon molecules are then oxidized, which means that they lose electrons, as electrons are transferred to the high energy electron acceptor NAD^+, producing the electron carrier NADH. This oxidation step helps produce 4 ATP molecules from ADP. That means, taking into account the initial investment of 2 ATP molecules, glycolysis has a net production of 2 ATP.

Table 4.1: **An Overview of Glycolysis**

Inputs	Outputs
Glucose (6-carbon molecule) 2 NAD^+ 2 ATP (energy) 4 ADP	2 pyruvate (3-carbon molecule) 2 NADH (electron carrier) 2 ADP 4 ATP (energy)

After glycolysis, the pyruvate can go down several different paths. If there is oxygen available, the pyruvate moves inside the mitochondrion to produce more ATP during further breakdown stages. In the absence of oxygen, the fermentation process begins.

Inside the Mitochondria

If oxygen is available, the next step of cellular respiration is moving the pyruvate into the mitochondria. The mitochondria have a double membrane. The inner membrane is known as the **cristae**, and is folded to form many internal layers. Some steps of cellular respiration occur in the cristae, while others take place in the **matrix**, the inner compartment of the mitochondrion that is filled with enzymes in a gel-like fluid.

Within the mitochondria the **Kreb's Cycle** or **citric acid cycle** occurs. The citric acid

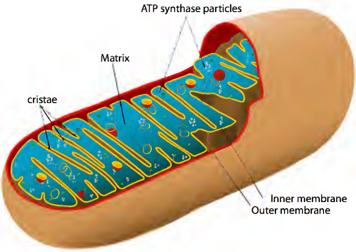

Figure 4.12: Most of the reactions of cellular respiration are carried out in the mitochondria. (6)

cycle is a series of oxidation steps that produce NADH and $FADH_2$, another type of electron carrier. These electron carriers will be used in the final step of cellular respiration. To begin the Kreb's Cycle, the 3-carbon pyruvate from glycolysis must be converted into a 2-carbon molecule, which then can enter the cycle. During the cycle carbon dioxide is produced. Two molecules of ATP are also produced per each initial glucose molecule. A graphic of the mitochondria is shown in **Figure** 4.12.

In the final steps of cellular respiration, the **electron transport chain** accepts the electrons from glucose that are being carried by NADH and $FADH_2$. These electrons are passed along the chain until they are finally combined with oxygen, which with the addition of hydrogen ions, becomes water. That is the key reason why this process only occurs in the presence of oxygen. Illustrated in **Figure** 4.13.

As the electrons move down the electron transport chain, energy is released and later used to synthesize ATP. The process of ATP synthesis is exactly the same as photosynthesis; hydrogen ions are pumped across the cristae of the mitochondria, forming a chemiosmotic gradient, and ATP synthase uses the energy of the movement of hydrogen ions back across the membrane, from high to low concentration, to make ATP.

Because oxygen is the final electron acceptor in this process, the electron transport chain can only occur in the presence of oxygen. This is known as **aerobic** respiration. However, there is not always enough oxygen present for aerobic respiration to occur. In this case, the next step after glycolysis will be fermentation instead of the citric acid cycle.

Table 4.2: **An Overview of the Citric Acid Cycle**

Inputs	Outputs
2 two-carbon molecules	4 CO_2
6 NAD^+	6 NADH (electron carrier)
2 FAD^+	2 $FADH_2$ (electron carrier)
2 ADP	2 ATP (energy)

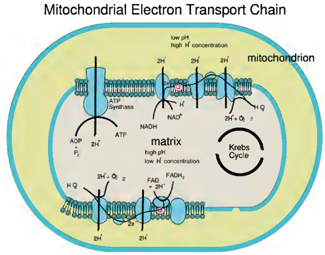

Figure 4.13: During electron transport, electrons from glucose (carried by NADH and $FADH_2$) are passed along until they are finally combined with oxygen, which with the addition of hydrogen ions, becomes water. Meanwhile, hydrogen ions are pumped across the cristae of the mitochondria, forming a gradient, and ATP synthase uses the energy of the movement of hydrogen ions back across the membrane, from high to low concentration, to make ATP. (8)

Fermentation

Sometimes cellular respiration is **anaerobic**, occurring in the absence of oxygen. In the process of **fermentation,** the NAD^+ is recycled so that is can be reused in the glycolysis process. No additional ATP is produced during fermentation, so the organism only obtains the two net ATP molecules per glucose from glycolysis.

Yeasts (single-celled eukaryotic organisms) carry on **alcoholic fermentation** in the absence of oxygen, making ethyl alcohol (drinking alcohol) and carbon dioxide. Alcoholic fermenta-

tion is central to bread baking. The carbon dioxide bubbles allow the bread to rise, and the alcohol evaporates. In wine making, the sugars of grapes are fermented to produce the wine.

Animals and some bacteria and fungi carry out **lactic acid fermentation.** Lactate (lactic acid) is a waste product of this process. Our muscles undergo lactic acid fermentation during strenuous exercise, when oxygen cannot be delivered to the muscles quickly enough. The buildup of lactate is what makes your muscles sore after vigorous exercise. Bacteria that produce lactate are used to make cheese and yogurt (**Figure** 4.14). Tooth decay is also accelerated by lactate from the bacteria that use the sugars in your mouth. In all these types of fermentation, the goal is the same: to recycle NAD^+ for glycolysis.

Figure 4.14: Products of fermentation include cheese (lactic acid fermentation) and wine (alcoholic fermentation). (12)

Lesson Summary

- Cellular respiration is the breakdown of glucose to release energy in the form of ATP.
- Glycolysis, the conversion of glucose into two 3-carbon pyruvate molecules, is the first step of cellular respiration.
- If oxygen is available, the pyruvate enters the mitochondria and goes through a series of reactions, including the citric acid cycle, to produce more ATP.
- If oxygen is not available, the pyruvate is reduced during the process of fermentation to free up more NAD^+ for glycolysis, and there is no net gain of ATP.

Review Questions

1. What are the products of alcoholic fermentation?
2. What is the metabolic process where glucose is ultimately converted to two molecules of pyruvate?
3. Why do your muscles get sore after vigorous exercise?
4. What is the purpose of fermentation?
5. Where does the citric acid cycle take place?
6. Write the chemical reaction for the overall process of cellular respiration.
7. Which is more efficient, aerobic or anaerobic cellular respiration?
8. What are the important electron-accepting enzymes in cellular respiration?
9. What is chemiosmosis?

Further Reading / Supplemental Links

- http://en.wikipedia.org/wiki/Cellular_respiration
- http://biology.clc.uc.edu/Courses/bio104/cellresp.htm
- http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookGlyc.html
- http://biology.clc.uc.edu/Courses/bio104/cellresp.htm
- http://www.science.smith.edu/departments/Biology/Bio231/glycolysis.html

Vocabulary

aerobic respiration Cellular respiration in the presence of oxygen.

alcoholic fermentation Fermentation in the absence of oxygen; produces ethyl alcohol (drinking alcohol) and carbon dioxide; occurs in yeasts.

anaerobic respiration Cellular respiration in the absence of oxygen; fermentation.

ATP A usable form of energy inside the cell; adenosine triphosphate.

cellular respiration The process in which the energy in food is converted into energy that can be used by the body's cells; in other words, glucose (and oxygen) is converted into ATP (and carbon dioxide and water).

citric acid cycle Middle phase of cellular respiration; formation of electron carriers occurs during this phase; also known as the Kreb's cycle.

cristae The inner membrane of the mitochondria. The inner membrane of the mitochondria.

electron transport chain Last phase of cellular respiration; used to power the formation of ATP occurs during this phase.

$FADH_2$ Electron carrier produced during the Kreb's cycle.

fermentation Anaerobic respiration in which NAD^+ is recycled so that is can be reused in the glycolysis process.

glycolysis First phase of cellular respiration; breakdown of glucose occurs during glycolysis; produces two 3-carbon pyruvate molecules.

lactic acid fermentation Anaerobic respiration that recycles NAD^+ for glycolysis; occurs in animals and some bacteria and fungi.

matrix The inner compartment of the mitochondrion that is filled with enzymes in a gel-like fluid.

mitochondria Organelle where cellular respiration occurs; known as the "powerhouse" of the cell because this is the organelle where the ATP that powers the cell is produced.

NADH Electron carrier produced during glycolysis and the citric acid cycle.

Points to Consider

- Now that we know how the cell gets its energy, we are going to turn our attention to cell division. Cell division is a highly regulated process.
- What do you think could happen if your cells divide uncontrollably?
- When new life is formed, do you think it receives all the DNA of the mother and the father?
- Why do you think you might need new cells throughout your life?

Image Sources

(1) http://en.wikipedia.org/wiki/Image:Osmotic_pressure_on_blood_cells_diagram.svg. Public Domain.

(2) http://commons.wikimedia.org/wiki/Image:Diffusion.en.jpg. Public Domain.

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Chapter 5

Cell Division, Reproduction, and DNA

5.1 Lesson 5.1: Cell Division

Lesson Objectives

- Explain why cells need to divide.
- List the stages of the cell cycle and explain what happens at each stage.
- List the stages of mitosis and explain what happens at each stage.

Check Your Understanding

- What is the cell theory?
- In what part of your cells is the genetic information located?

Introduction

Imagine the first stages of a life. In humans, a sperm fertilizes an egg, forming the first cell. From that one cell, an entire baby with trillions of cells will develop. How does a new life go from one cell to so many? The cell divides in half, creating two cells. Then those two cells divide. The new cells continue to divide and divide. One cell becomes two, then four, then eight, and so on (**Figure** 5.1). Rapid cell division allows the development of new life, but cell division must be tightly regulated. If the body's close regulation of cell division is disrupted later in life, diseases such as cancer can develop. Cancer involves cells that divide in an uncontrolled manner. Therefore, much research into cell division is underway across the globe in effort to further understand this process and find a cure for cancer.

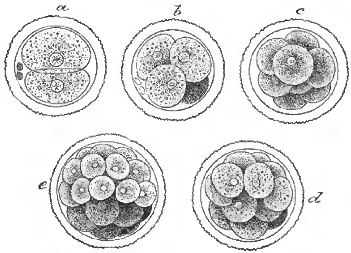

Figure 5.1: Cells divide repeatedly to produce an embryo. Previously the one-celled zygote divided to make two cells (a). Each of the two cells divides to yield four cells (b), then the four cells divide to make eight cells(c), and so on. Through cell division, an entire embryo forms from one initial cell. (17)

Why Cells Divide

Besides the development of a fetus, there are many other reasons that cell division is necessary to life. To grow and develop, you must form new cells. Imagine how often your cells must divide during a growth spurt. Growing just an inch requires countless cell divisions.

Another reason for cell division is to repair damaged cells. Imagine you cut your finger. After the scab forms, it will eventually disappear and new skin cells will grow to repair the wound. Where do these cells come from? Remember that according to the cell theory, all cells must come from preexisting cells. In order to make new skin cells, some of your existing skin cells had to undergo cell division.

Besides suffering physical damage, your cells can simply wear out. Over time you must replace old and worn-out cells. Again, cell division is essential to this process. You can only make new cells by dividing similar preexisting cells.

The Cell Cycle

The process of cell division in eukaryotic cells is carefully regulated. The **cell cycle** which in essence is the lifecycle of a cell, is composed of a series of steps that lead to cell division (**Figure** 5.2). These steps can be divided into two main components: interphase and mitosis.

Interphase is when the cell mainly performs its “everyday” functions; for example, it is when a kidney cell does what a kidney cell is supposed to do. On the other hand, mitosis is when the cell prepares to become two cells. Some cells, like nerve cells, do not complete the cell cycle and divide, while others divide repeatedly.

Most of the cell cycle consists of **interphase,** the time between cell divisions. During this time the cell carries out its normal functions and prepares for the next stage. Interphase can be divided into three stages: the first growth phase (G1), the synthesis phase (S), and the second growth phase (G2). During the G1 stage, the cell doubles in size and doubles the number of organelles. Next, during the S stage, the DNA is replicated. In other words, an identical copy of all the cell’s DNA is made. This ensures that each new cell that results after cell division has a set of genetic material identical to that of the parental cell. DNA replication will be further discussed in lesson 3. Finally, in the G2 stage proteins are synthesized that will aid in cell division. In the end of interphase, the cell is ready to enter the mitotic phase.

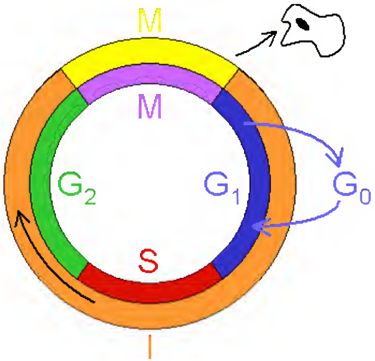

Figure 5.2: The cell cycle is the repeated process of growth and division. Notice that most of the cell cycle is spent in interphase (G1, S, and G2) (I). (2)

During the mitotic phase, nuclear division occurs, which is known as **mitosis**. Also **cytokinesis**, the division of the cytoplasm, occurs. After cytokinesis, cell division is complete and two genetically identical daughter cells have been produced from one parent cell. The term ”genetically identical” refers to the fact that each resulting cell has an identical set of DNA,

and this DNA is also identical to that of the parent cell.

Mitosis and Chromosomes

During cell division, two nuclei must form during the process of mitosis, so that one nucleus can be given to each of cells that form from cytokinesis. In the nucleus, the genetic information of the cell, DNA, is stored. The copied DNA needs to be moved into a new nucleus for the new cell to have a correct set of genetic instructions.

The DNA in the nucleus is condensed into **chromosomes**, structures composed of DNA wrapped around proteins. Each organism has a unique number of chromosomes; in human cells our DNA is divided up into 23 pairs of chromosomes. When a cell is not undergoing division, such as during interphase, the complex of DNA and proteins is a tangled mass of threads known as chromatin. As mitosis begins, however, the DNA becomes tightly coiled into the chromosomes which become visible under a microscope.

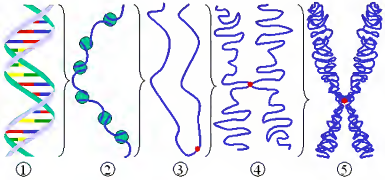

Figure 5.3: The DNA double helix wraps around histone proteins (2) and tightly coils a number of times to form a condensed chromosome (5). The chromosomes contains millions of nucleotide bases. This figure illustrates the complexity of the coiling process. The red dot shows the location of the centromere, where the microtubules attach during mitosis and meiosis. (16)

As mentioned previously, the DNA is replicated during the S stage of interphase. Each chromosome now has two identical molecules of DNA, called sister **chromatids,** forming the "X" shaped molecule depicted in **Figure** 5.3. During mitosis, the two sister chromatids must be split apart to give rise to two identical chromosomes (in essence, each resulting chromosome is made of 1/2 of the "X"). Through this process, each daughter cell receives one copy of each chromosome.

Mitosis is divided into four phases: prophase, metaphase, anaphase, and telophase. During prophase, the chromosomes become tightly wound and become visible under the microscope. Also, the nuclear envelop dissolves, and the spindle begins to form. The **spindle** is a structure containing many fibers that helps to move the chromosomes. By late prophase,

the chromosomes are attached to the spindle fibers. The spindle fibers will later pull the chromosomes into alignment.

During metaphase, the chromosomes line up across the center of the cell. The chromosomes line up in a row, one on top of the next. During anaphase, the two sister chromatids of each chromosome separate, resulting in two sets of identical chromosomes. During telophase, the spindle dissolves and nuclear envelopes form around the chromosomes. The drawings of **Figure** 5.4 show this process. This is further shown in **Figure** 5.5. Each new nucleus contains the exact same number and types of chromosomes as the original cell. The cell is now ready for cytokinesis, producing two genetically identical cells, each with its own nucleus.

Lesson Summary

- Cells divide for growth, development, reproduction and replacement of injured or worn-out cells.
- The cell cycle is a serious of regulated steps by which a cell divides.
- During mitosis, the newly duplicated chromosomes are divided into two daughter nuclei.

Review Questions

1. In what phase of mitosis are chromosomes moving toward opposite sides of the cell?
2. In what phase of mitosis do the duplicated chromosomes condense?
3. What step of the cell cycle is the longest?
4. What is the term for the division of the cytoplasm?
5. What happens during the S stage of interphase?
6. Interphase used to be considered the "resting" stage of the cell cycle. Why is this not correct?
7. What are some reasons that cells divide?
8. During what stage of the cell cycle does the cell double in size?
9. Why must cell division be tightly regulated?
10. What is the purpose of mitosis?

Further Reading / Supplemental Links

- http://en.wikipedia.org/wiki/Mitosis
- http://www.biology.arizona.edu/Cell_bio/tutorials/cell_cycle/cells3.html
- http://biology.clc.uc.edu/courses/bio104/mitosis.htm
- http://en.wikipedia.org/wiki/Cell_cycle
- http://www.cellsalive.com/mitosis.htm

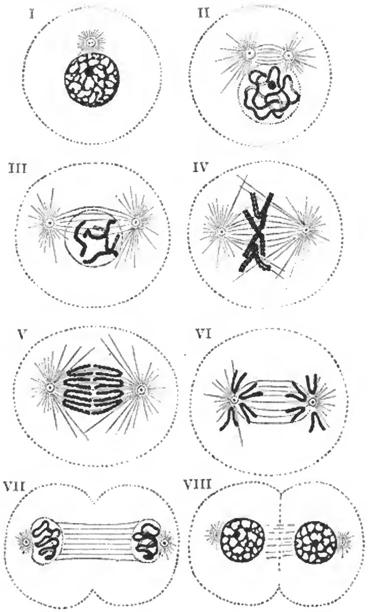

Figure 5.4: An overview of mitosis: during prophase (I and II) the chromosomes condense, during metaphase the chromosomes line up (III and IV), during anaphase the sister chromatids are pulled to opposite sides of the cell (V and VI), during telophase the nuclear envelope forms (and VII and VIII). (14)

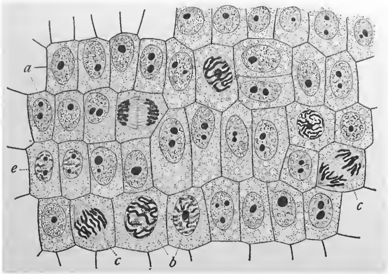

Figure 5.5: This is a picture of dividing plant cells. Cell division in plant cells differs slightly from animal cells as a cell wall must form. Note that most of the cells are in interphase. Can you find examples of the different stages of mitosis? (7)

- http://www.wisc-online.com/objects/index_tj.asp?objID=AP13604

Vocabulary

anaphase Third phase of mitosis where sister chromatids separate and move to opposite sides of the cell.

cell cycle Sequence of steps in eukaryotic cells that leads to cell division.

chromatin Complex of DNA and proteins that is visible when a cell is not dividing.

chromosomes DNA wound around proteins; forms during prophase of mitosis and meiosis.

cytokinesis Division of the cytoplasm after mitosis or meiosis.

interphase Stage of the cell cycle when DNA is synthesized and the cell grows; composed of the first three phases of the cell cycle.

metaphase Second phase of meiosis where the chromosomes are aligned in the center of the cell.

mitosis Sequence of steps in which a nucleus is divided into two daughter nuclei, each with an identical set of chromosomes.

prophase Initial phase of mitosis where chromosomes condense, the nuclear envelope dissolves and the spindle begins to form.

spindle Fibers that move chromosomes during mitosis and meiosis.

telophase Final phase of mitosis where a nuclear envelop forms around each of the two sets of chromosomes.

Points to Consider

- How might a cell without a nucleus divide?
- How are new cells made that incorporate the DNA of two parents?

5.2 Lesson 5.2: Reproduction

Lesson Objectives

- Name the types of asexual reproduction.
- Explain the advantage of sexual reproduction.
- List the stages of meiosis and explain what happens in each stage.

Check Your Understanding

- Can something that does not reproduce still be considered living?
- What stores the genetic information that is passed on to offspring?
- How many chromosomes are in the human nucleus?

Introduction

Can an organism be considered alive if it cannot make the next generation? For a species to survive, **reproduction,** the ability to make the next generation, is absolutely necessary. For a species to be successful, it not only needs to be well adapted to its environment, but also needs to be successful at reproduction. Reproduction allows a population of organisms to pass on their genetic information to the next generation. There are many different ways that organisms reproduce, and these methods are categorized as either sexual or asexual reproduction. There are advantages and disadvantages to each method, but the result is always the same: a new life begins.

Asexual Reproduction

Some organisms can reproduce **asexually,** meaning that the offspring have a single parent and share the exact same genetic material as the parent. The advantage of asexual reproduction is that it can be very quick and does not require the meeting of two individuals of the opposite sexes. The disadvantage of asexual reproduction is that it does not involve genetic recombination, a process that can result in an adaptive new set of traits. For example, you might inherit one advantageous trait from your maternal grandmother, another adaptive trait from your paternal grandmother, and other adaptive traits from your paternal grandfather. You have the benefit of the many genes from two lineages combining in a new way. An organism that is born through asexual reproduction, however, only has the DNA from one parent, and it is the exact copy of that parent. Therefore, no new combinations of traits can happen.

Prokaryotic organisms, which as you might recall are single-celled, reproduce asexually. Bacteria reproduce through **binary fission,** where they basically divide in half (**Figure** 5.6). First, their chromosome replicates and the cell enlarges. After cell division, the two new cells each have one identical chromosome. Mitosis is not necessary as there is no nucleus. Then new membranes form to separate the two cells. This simple process is beneficial to the bacteria, allowing very rapid reproduction.

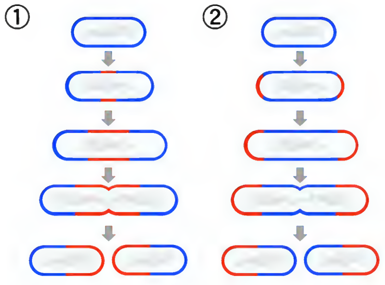

Figure 5.6: Bacteria reproduce by binary fission. Shown is one bacterium reproducing and becoming two bacteria. (1)

There are also several animals that can reproduce asexually. Flatworms can divide in two, then each half regenerates into a new flatworm identical to the original. Many types of insects, fish, and lizards (**Figure** 5.7)can reproduce asexually through parthenogenesis.

Parthenogenesis is a process by which an unfertilized egg cell grows into a new organism. The resulting organism has half the amount of genetic material of the parent, as the starting egg cell has half the amount of DNA compared to the parent. Parthenogenesis is common in honeybees. The fertilized eggs in a hive become workers, while the unfertilized eggs become drones.

Egg cells (and also sperm cells) are produced through a cell division mechanism in which the amount of DNA is halved. This process is called meiosis and will be discussed shortly.

Figure 5.7: This Komodo dragon was born by parthenogenesis. (5)

Sexual Reproduction

During sexual reproduction, two parents are involved. Most animals are dioecious, meaning there is a separate male and female sex, with the male producing sperm and the female producing eggs. When a sperm and egg meet, a **zygote,** the first cell of a new organism, is formed (**Figure** 5.8). The zygote will divide and grow into the embryo.

Animals often have **gonads,** specialized organs that produce eggs or sperm. The male gonads are the **testes,** which produce the sperm, and the female gonads are the **ovaries,** which produce the eggs. Sperm and egg, the two sex cells, are known as **gametes**, and unite through a variety of methods. Fish and other aquatic animals release their gametes in the water, which is called **external fertilization** (**Figure** 5.9). Animals that live on land, however, usually practice **internal fertilization**. Typically males have a penis that deposits sperm into the vagina of the female. Other anatomical features can accomplish the same goal; birds, for example, have a chamber called the cloaca that they place close to another

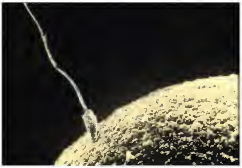

Figure 5.8: During sexual reproduction, a sperm fertilizes an egg. (4)

bird's cloaca to deposit sperm. Whatever method of fertilization is used, the net result is the same: a zygote that contains DNA from both the male and female.

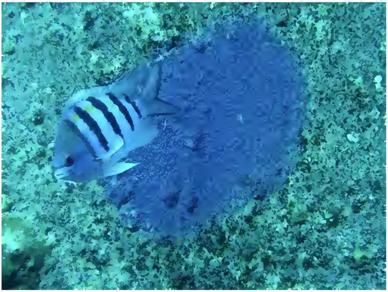

Figure 5.9: This fish guards her eggs, which will be fertilized externally. (15)

Plants also can reproduce sexually, but their reproductive organs are somewhat different than animals' gonads. Most plants are flowering plants, meaning their reproductive parts are contained in a flower. The sperm is contained in the pollen, while the egg is contained in the ovary deep within the flower. The sperm can reach the egg through several methods. In self-pollination, the egg is fertilized by the pollen of same flower. In **cross-pollination**, the sperm from the pollen from one flower fertilizes the egg of another flower. Cross-pollination increases the genetic diversity of the population. Like other types of sexual reproduction, cross-pollination allows new combinations of traits. Cross-pollination can be achieved when pollen is carried by the wind to another flower, or many flowers rely on animal pollinators, like honeybees, or butterflies (**Figure** 5.10) to carry the pollen from flower to flower.

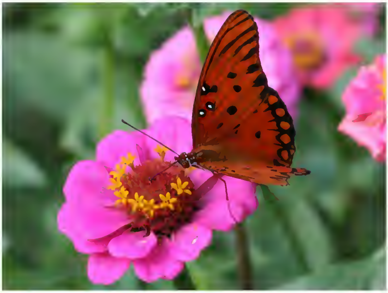

Figure 5.10: Butterflies receive nectar when they deposit pollen into flowers, resulting in cross-pollination. (8)

Fungi can also reproduce sexually, but instead of female and male sexes, they have (+) and (-) strains. When the filaments of a (+) and (-) fungi meet, the zygote is formed. As with the sexual reproduction in plants and animals, each zygote receives DNA from two parent strains.

Meiosis and Gametes

The formation of gametes, the reproductive cells such as sperm and egg, is necessary for sexual reproduction. As gametes are produced, the number of chromosomes must be reduced to half. In humans, our cells have 23 pairs of chromosomes, and each chromosome within a pair is called a **homologous chromosome.** For each of the 23 chromosome pairs, you received one chromosome from your father and one chromosome from your mother. The homologous chromosomes have the same genes, although there might be alternate forms of each gene, called **alleles**, which vary between the chromosomes. These homologous chromosomes are separated during gamete formation, therefore gametes have only 23 chromosomes, not 23 pairs. This separation of chromosomes is random. The probability or chance that a particular allele will be in a gamete is 1 in 2. The gamete may receive either the paternal allele (inherited from the father) or the maternal allele (inherited from the mother). This random separation of chromosomes (and therefore alleles) occurs for each chromosome, resulting in an widely varied combination of chromosomes in each gamete. With 23 pairs of chromosomes, this results in over 8 million different combinations of chromosomes a gamete.

Haploid vs. Diploid

A cell with two sets of chromosomes is **diploid**, referred to as $2n$, where n is the number of sets of chromosomes. A cell with one set of chromosomes, such as a gamete, is **haploid,** referred to as n. So when a haploid sperm and a haploid egg combine, a diploid zygote will be formed; in essence, when a zygote is formed, half of the DNA in the diploid zygote comes from each parent. The process of cell division that reduces the chromosome number by half is called **meiosis.**

Meiosis

Prior to meiosis, DNA replication occurs, so each chromosome contains two **sister chromatids** that are identical to the original chromosome. Meiosis is divided into two nuclear divisions: meiosis I and meiosis II. Each of these nuclear divisions shares many aspects of mitosis and can be divided into the same phases: prophase, metaphase, anaphase, and telophase; however, between the two divisions, DNA replication does not occur. Through this process, one diploid cell will divide into four haploid cells.

Meiosis I

During meiosis I, the pairs of homologous chromosomes are separated from each other. During prophase I, the homologous chromosomes line up together. During this time, **crossing-over** can occur (**Figure** 5.11), the exchange of DNA between homologous chromosomes. Crossing-over increases the new allele combinations in the gametes. Without crossing-over, the offspring would always inherit all of the many alleles on one of the homologous chromosomes. Because of crossing over, the alleles on the homologous chromosomes can be scrambled to pass on unique combinations of alleles on the chromosome. Also during prophase I, the spindle forms and the chromosomes condense as they coil up tightly. The spindle has the same function as in mitosis.

During metaphase I, the homologous chromosomes line up in pairs in the middle of the cell; that is, both chromosome of a pair will line up together. The maternal chromosomes or paternal chromosomes can each attach to either side of the spindle. The assignment of which side is random, so all the maternal or paternal chromosomes do not end up in one gamete. The gamete will contain some chromosomes from the mother and some chromosomes from the father. Note this is different than during metaphase of mitosis; although chromosomes still line up during mitosis, the sister chromatids are separated, and each cell obtains both the maternal and paternal chromosome of each pair.

During anaphase I, the homologous chromosomes separate. In telophase I, the spindle dissolves, but a new nuclear envelop does not need to form. That's because after a brief resting stage, the nucleus will divide again. No DNA replication happens between meiosis I and

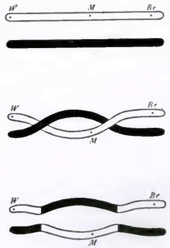

Fig. 65. Scheme to illustrate double crossing over.

Figure 5.11: During crossing-over, segments of DNA are exchanged between sister chromatids. Notice how this can result in an allele (M) on one sister chromatid being moved onto the other sister chromatid. (19)

meiosis II as the chromosomes are already duplicated, carrying sister chromatids.

Meiosis II

During meiosis II, the sister chromosomes are separated and the gametes are generated. During prophase II, the chromosomes condense. In metaphase II the chromosomes line up one on top of the next along the equator, or middle of the cell. During anaphase II, the sister chromatids separate. After telophase and cytokinesis, each cell has divided again. Therefore, meiosis results in four cells with half the DNA of the parent cell (**Figure** 5.12). In our cells, the parent cell has 46 chromosomes, whereas the cells that result from meiosis have 23 chromosomes. These cells will become gametes. (See **Figure** 5.13).

Lesson Summary

- Organisms can reproduce sexually or asexually.
- The gametes in sexual reproduction must have half the DNA of the parent.
- Meiosis is the process of nuclear division to form gametes.

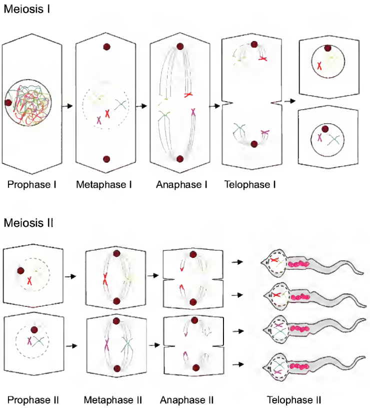

Figure 5.12: An overview of meiosis. (12)

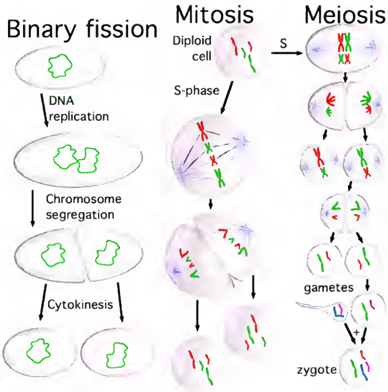

Figure 5.13: A comparison between binary fission, mitosis, and meiosis. (11)

Review Questions

1. What is parthogenesis?
2. How can organisms reproduce asexually?
3. How would sexual reproduction in a lizard be different than a fish?
4. Are the viable eggs that birds lay need to be fertilized externally?
5. How do most plants reproduce sexually?
6. What is the purpose of meiosis?
7. What is the advantage of sexual reproduction over asexual reproduction?
8. If an organism has 12 chromosomes in its cells, how many chromosomes will be in its gametes?
9. During what phase of meiosis do homologous chromosomes separate?
10. In what phase of meiosis do homologous chromosomes pair up?

Further Reading / Supplemental Links

- http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookmeiosis.html
- http://www.biology.arizona.edu/Cell_BIO/tutorials/meiosis/page3.html
- http://www.cellsalive.com/meiosis.htm
- http://www.youtube.com/watch?v=MqaJqLL49a0&NR=1
- http://en.wikipedia.org/

Vocabulary

allele An alternative form of a gene.

asexual reproduction A form of reproduction in which a new individual is created by only one parent.

binary fission An asexual form of reproduction where a cell splits into two daughter cells.

crossing-over Exchange of DNA segments between homologous chromosomes; occurs during prophase I of meiosis.

cross-pollination Sexual reproduction in plants where sperm from the pollen of one flower is received by the ovary of another flower.

diploid When a cell has two sets of chromosomes.

gametes Cells involved in sexual reproduction; typically egg and sperm cells.

gonads Organ that produces gametes, such as the ovaries and testes.

haploid When a cell has only one set of chromosomes, typical of a gamete.

internal fertilization Reproduction occurs through the internal deposit of gametes.

external fertilization Reproduction where the eggs are fertilized outside the body.

meiosis Nuclear division that results in haploid gametes.

ovaries Female gonads in animals that produce eggs.

parthenogenesis Reproduction where an unfertilized egg develops into a new individual.

sexual reproduction Reproduction where gametes from two parents combine to make an individual with an unique set of genes.

sister chromatids Two genetically identical chromosome segments that form after DNA replication.

testes Male gonads in animals that produce sperm.

zygote Single cell that is formed after the fertilization of an egg; the first cell of a new organism.

Points to Consider

- What must be replicated prior to mitosis?
- How do you think DNA might be replicated?
- What might happen if there is a mistake during DNA replication?

5.3 Lesson 5.3: DNA, RNA, and Protein Synthesis

Lesson Objectives

- Explain the chemical composition of DNA.
- Explain how DNA synthesis works.
- Explain how proteins are coded for and synthesized.
- Describe the three types of RNA and the functions of each.

Check Your Understanding

- What is the purpose of DNA?
- When is DNA replicated?

Introduction

Much research in the past fifty years has been focused on understanding the genetic material, DNA. Understanding how DNA works has brought with it many useful technologies. DNA fingerprinting allows police to match a criminal to a crime scene. Transgenic crops, or crops that contain altered DNA, have improved yields for farmers. And you can now test your DNA to find out the chance that your future children may be at risk for a rare genetic disorder. Although we can do some really complicated things with DNA, the chemical structure of DNA is remarkably simple and elegant.

What is DNA?

DNA, is the material that makes up our chromosomes and stores our genetic information. This genetic information is basically a set of instructions that tell your cells what to do. DNA is an abbreviation for deoxyribonucleic acid. As you may recall, nucleic acids are the class of chemical compounds that store information. The *deoxyribo* part of the name refers to the name of the sugar that is contained in DNA, deoxyribose.

The chemical composition of DNA is a polymer, or long chain, of nucleotides. **Nucleotides** are composed of a phosphate group, a 5-carbon sugar, and a nitrogen-containing base. The only difference between each nucleotide is the identity of the base. There are only four possible bases that make up each DNA nucleotide: adenine (A), guanine (G), thymine (T), and cytosine (C). The various sequences of these four bases make up the genetic code of your cells. It may seem strange that there are only four letters in the "alphabet" of DNA. But since your chromosomes contain millions of nucleotides, there are many, many different combinations possible with those four letters.

But how do all these pieces fit together? James Watson and Francis Crick won the Nobel Prize in 1962 for piecing together the structure of DNA. Together with the work of Rosalind Franklin and Maurice Wilkins, they determined that the structure of DNA is two strands of nucleotides in a **double helix** (**Figure** 5.14), or a two-stranded spiral, with the sugar and phosphate groups on the outside, and the paired bases connecting the two strands on the inside of the helix (**Figure** 5.15).

The bases do not pair randomly, however. When Erwin Chargaff looked closely at the base content in DNA, he noticed that the percentage of adenine (A) in the DNA always equaled the percentage of thymine (T), and the percentage of guanine (G) always equaled the percentage of cytosine (C). Watson and Crick's model explained this result by suggesting

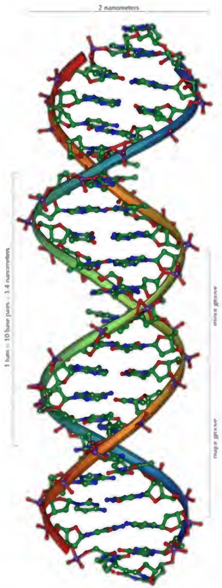

Figure 5.14: DNA's three-dimensional structure is a double helix. The hydrogen bonds between the bases at the center of the helix hold the helix together. (22)

that A always pairs with T and G always pairs with C in the DNA helix. Therefore A and T, and G and C, are complementary bases. If one DNA strand reads ATGCCAGT, the other strand would be made up the complementary bases: TACGGTCA. These base pairing rules state that in DNA, A always pairs with T, and G always pairs with C.

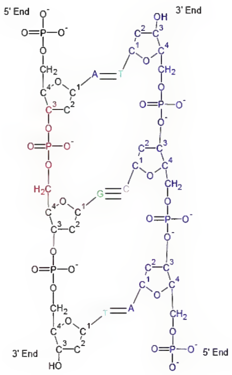

Figure 5.15: The chemical structure of DNA includes a chain of nucleotides consisting of a 5-carbon sugar, a phosphate group, and a nitrogen base. Notice how the sugar and phosphate form the backbone of DNA (one strand in blue), with the hydrogen bonds between the bases joining the two strands. (3)

DNA Replication

The base paring rules are crucial for the process of replication. **DNA replication** is the process by which DNA is copied to form an identical daughter molecule of DNA. During DNA replication, the DNA helix unwinds as the weak hydrogen bonds between the paired bases are broken. The two single strands of DNA then each serve as a template for a new stand to be synthesized. The new nucleotides are placed in the right order because of the base pairing rules. The new set of nucleotides then join together to form a new strand of DNA. The process results in two DNA molecules, each with one old strand and one new strand of DNA. Therefore, this process is known as **semiconservative replication** because one strand is conserved in each new DNA molecule (**Figure** 5.16).

Figure 5.16: DNA replication occurs by the DNA strands “unzipping”, and the original strands of DNA serve as a template for new nucleotides to join and form a new strand. (21)

Protein Synthesis

The code of DNA, stored in the base sequences, contains the instructions for the order of assembly of amino acids to make proteins. Each strand of DNA has many, many separate sequences that code for the production of a specific protein. These discrete units of DNA that contain code for the creation of one protein are called **genes.** Proteins are made up of units called **amino acids**, and the sequence of bases in DNA codes for the specific sequence of amino acids in a protein.

There are about 22,000 genes in every human cell. Does every human cell have the same genes? Yes. Does every human cell use the same genes to make the same proteins? No. In a multicellular organism, such as us, cells have specific functions because they have different proteins, and they have different proteins because different genes are expressed in different cell types. Think of **gene expression** as if all your genes usually are ”turned off.” Each cell type only ”turns on” (or expresses) the genes that have the code for the proteins it needs to use. So different cell types ”turn on” different genes, allowing different proteins to be made, giving different cell types different functions.

However, DNA does not directly coordinate the production of proteins. Remember that DNA is found in the nucleus of the cell, but proteins are made on the ribosomes in the cytoplasm. How do the instructions in the DNA get out to the cytoplasm so that proteins

can be made? DNA sends out a message, in the form of **RNA** (ribonucleic acid), describing how to make the protein. There are three types of RNA directly involved in protein synthesis. Messenger RNA (mRNA) carries the instructions from the nucleus to the cytoplasm. The other two forms of RNA, ribosomal RNA (rRNA) and transfer RNA (tRNA) are involved in the process of ordering the amino acids to make the protein. This process is called translation and will be discussed below. All three RNAs are nucleic acids and are therefore made of nucleotides. The RNA nucleotide is very similar to the DNA nucleotide except for the fact that it contains a different kind of sugar, ribose, and the base uracil (U) replaces the thymine (T) found in DNA.

mRNA is created in a method very similar to DNA synthesis. mRNA is also made up of nucleotide units. The double helix unwinds and the nucleotides follow basically the same base paring rules to form the correct sequence in the mRNA. This time, however, U pairs with each A in the DNA. In this manner, the genetic code is securely passed on to the mRNA. The process of constructing a mRNA molecule from DNA is known as **transcription** (**Figures** 5.17 and 5.18).

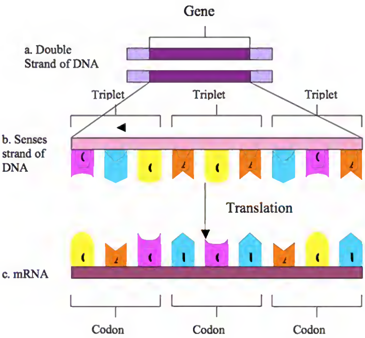

Figure 5.17: Each gene (a) contains triplets of bases (b) that are transcribed into RNA (c). Every triplet, or codon, encodes for a unique amino acid. (20)

The mRNA is directly involved in the protein synthesis process and tells the ribosome (**Figure** 5.19) how to assemble a protein. The base code in the mRNA dictates the order of the amino acids in the protein. But because there are only 4 bases in mRNA and 20 different amino acids, one base cannot directly code for one amino acid. The genetic

Figure 5.18: Base-pairing ensures the accuracy of transcription. Notice how the helix must unwind for transcription to take place. (10)

code in mRNA is read in "words" of three letters (triplets), called **codons.** For example, GGU encodes for the amino acid glycine, while GUC encodes for valine. This genetic code is universal and used by almost all living things. These codons are read in the ribosome, the organelle responsible for protein synthesis. In the ribosome, tRNA reads the code and brings a specific amino acid to attach to the growing chain of amino acids, which is a protein in the process of being synthesized. Each tRNA carries only one type of amino acid and only recognizes one specific codon. The process of reading the mRNA code in the ribosome to synthesize a protein is called **translation** (**Figure** 5.20). There are also three codons, UGA, UAA, and UAG, which indicate that the protein is complete. They do not have an associated amino acid. As no amino acid can be added to the growing polypeptide chain, the protein is complete. The chart in **Figure** 5.21 should be of use in this area of study.

Mutations

The process of DNA replication is not always 100% accurate, and sometimes the wrong base is inserted in the new strand of DNA. A permanent change in the sequence of DNA is known as a **mutation** (**Figure** 5.22).A mutation may have no effect on the phenotype or can cause the protein to be manufactured incorrectly, which can affect how well the protein works, or whether it works at all. Usually the loss of a protein function is detrimental to the organism.

However, in rare circumstances, the mutation can be beneficial. For example, suppose a mutation in an animal's DNA causes the loss of an enzyme that makes a dark pigment in the animal's skin. If the population of animals has moved to a light colored environment, the animals with the mutant gene would have a lighter skin color and be better camouflaged. So in this case, the mutation was beneficial.

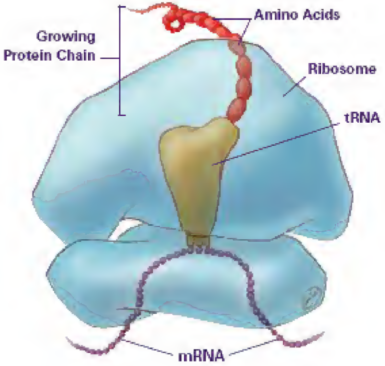

Figure 5.19: Ribosomes translate RNA into a protein with a specific amino acid sequence. The tRNA binds and brings to the ribosome the amino acid encoded by the mRNA. Ribosomes are made of rRNA and proteins. (6)

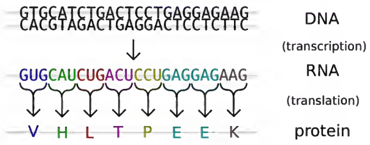

Figure 5.20: This summary of how genes are expressed shows that DNA is transcribed into RNA, which is translated in turn to protein. (13)

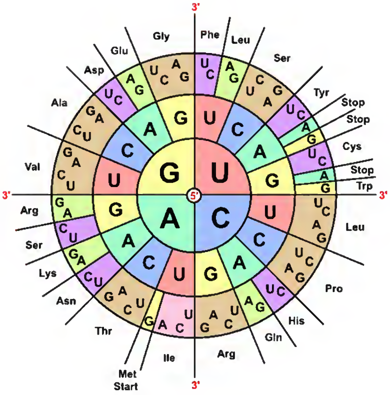

Figure 5.21: This chart shows the genetic code used by all organisms. For example, an RNA codon reading GUU would encode for a valine (Val) according to this chart. Start at the center for the first base of the three base codon, and work your way out. Notice for valine, the second base is a U and the third base of the codon may be either a G, C, A, or U. Similarly, glycine (Gly) is encoded by a GGG, GGA, GGC, and GGU. (9)

There are many possible types of mutations possible in chromosomes. In the case of a point mutation, there is a change in a single nucleotide. Other mutations can be more dramatic. A large segment of DNA can be deleted, duplicated, inverted, or inserted in the wrong place. These mutations usually result in a non-functional protein, or a number of non-functional proteins. A deletion is when a segment of DNA is lost, so there is a missing segment in the chromosome. A duplication is when a segment is repeated, creating a longer chromosome. In an inversion, the segment of DNA is flipped and then reattached to the chromosome. An insertion is when a segment of DNA from one chromosome is added to another, unrelated chromosome.

Even if a single base is changed, it can cause a major problem. The substitution of a single base is called a point mutation. Sickle cell anemia is an example of a condition caused by a point mutation in the hemoglobin gene. In this gene, just the one base change causes a different amino acid to be inserted in the hemoglobin protein, causing the protein to fold differently and not function properly in carrying oxygen in the bloodstream.

If a single base is deleted, it can also have huge effects on the organism because this would cause a frameshift mutation. Remember that the bases are read in groups of three by the tRNA. If the reading frame gets off by one base, the resulting sequence will consist of an entirely different set of codons. The reading of an mRNA is like reading three letter words of a sentence. Imagine you wrote "big dog ate red cat". If you take out the second letter, the frame will be shifted so now it will read "bgd oga ter edc at." One single deletion makes the whole "sentence", or mRNA, not read correctly.

Many mutations are not caused by errors in replication. Mutations can happen spontaneously and they can be caused by **mutagens** in the environment. An example of a mutagen is radiation. High levels of radiation can alter the structure of DNA. Also, some chemicals, such as those found in tobacco smoke, can be mutagens. Sometimes mutagens can also cause cancer. Tobacco smoke, for example, is often linked to lung cancer.

Lesson Summary

- DNA stores the genetic information of the cell in the sequence of its 4 bases: adenine, thymine, guanine, and cytosine.
- The information in a small segment of DNA, a gene, is sent by mRNA to the ribosome to synthesize a protein.
- Within the ribosome, tRNA reads the mRNA in sets of three bases (triplets), called codons, which encode for the specific amino acids that make up the protein.
- A mutation is a permanent change in the sequence of bases in DNA.

Review Questions

1. Translate the following segment of DNA into RNA: AGTTC

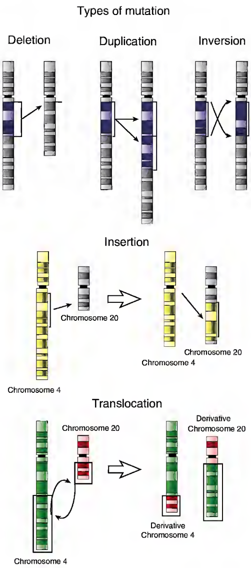

Figure 5.22: Mutations can arise in DNA through deletion, duplication, inversion, insertion, and translocation within the chromosome. A deletion is when a segment of DNA is lost from the chromosome. A duplication is when a segment is repeated. In an inversion, the segment of DNA is flipped and then re-annealed. An insertion or translocation can cause DNA from one chromosome to be added onto another, unrelated chromosome. (18)

2. Write the complimentary DNA nucleotides to this strand of DNA: GGTCCA
3. What makes up a nucleotide?
4. Nucleotides are subunits of which polymers?
5. Amino acids are subunits that make up what polymer?
6. Describe the process of DNA replication
7. Name a mutagen.
8. What is made in the process of transcription?
9. What is made in the process of translation?
10. How does RNA encode for proteins?

Further Reading / Supplemental Links

- http://www.phschool.com/science/biology_place/biocoach/dnarep/intro.html
- http://nobelprize.org/educational_games/medicine/dna_double_helix/readmore.html
- http://www.biostudio.com/demo_freeman_protein_synthesis.htm
- http://learn.genetics.utah.edu/units/basics/transcribe/
- http://www-class.unl.edu/biochem/gp2/m_biology/animation/gene/gene_a2.html
- http://learn.genetics.utah.edu/units/basics/builddna/
- http://enwikipedia.org/
- http://sickle.bwh.harvard.edu/scd_background.html

Vocabulary

amino acid The units (monomers)that combine to make proteins.

DNA Deoxyribonucleic acid; a nucleic acid that is the genetic material of all organisms.

DNA replication The synthesis of new DNA; occurs during the S phase of the cell cycle.

double helix Describes the shape of DNA as a double spiral; similar to a spiral staircase.

gene The inherited unit of DNA that encodes for one protein (or one polypeptide).

mutagen A chemical or physical agent that can cause changes to accumulate in DNA.

mutation A change in the nucleotide sequence of DNA.

nucleotide The units that make up DNA; consists of a 5-carbon sugar, a phosphate group, and a nitrogen-containing base

RNA The nucleic acid that carries the information stored in DNA to the ribosome.

semiconservative replication Describes how the replication of DNA results in two molecules of DNA, each with one original strand and one new strand.

transcription The synthesis of a RNA that carries the information encoded in the DNA.

translation The synthesis of proteins as the ribosome reads each codon in RNA, which code for a specific amino acid.

Points to Consider

- Your cells have "proofreaders" that replace mismatched pairs that occurred during DNA synthesis. How would that affect the rate of mutation in your body?
- There are many diseases due to mutations in the DNA. These are known as genetic diseases, and many can be passed onto the next generation. Think about how a single base change cause a huge medical problem like sickle cell anemia.
- Your DNA contains the instructions to make you. So is everyone's DNA different? Can it be used to distinguish individuals, like a fingerprint?

Image Sources

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Chapter 6

Genetics

6.1 Lesson 6.1: Gregor Mendel and the Foundations of Genetics

Lesson Objectives

- Explain Mendel's law of segregation.
- Draw a Punnett square to make predictions about the traits of the offspring of a simple genetic cross.

Check Your Understanding

- What is the genetic material of our cells?
- How does meiosis affect the chromosome number in gametes?

Introduction

For centuries people have been fascinated with the inheritance of human traits. People might say, "You have your father's eyes." or, "You have red hair like your granddad; it must have skipped a generation." These comments show an appreciation of the laws of human inheritance. We inherit traits from our ancestors, and sometimes traits can stay hidden and show up in later generations. **Genetics,** the study of inheritance, explains how traits are passed on from one generation to the next. Due to recent developments in the field of genetics, we can now seek to understand the inheritance of disease. People today may ask "What are the chances my child will have cystic fibrosis?" and "What is the likelihood that I may have breast cancer if my grandmother had it?" Genetic counselors are trained to address

families' questions about the probabilities of passing on a genetic disorder. When genetic counselors sit down with families to discuss these types of questions, it's amazing that their answers are derived from the fundamentals of genetics discovered by a monk in the 1800s.

Figure 6.1: Gregor Mendel (9)

Mendel's Experiments

The laws of heredity were first developed by an Austrian monk, Gregor Mendel (**Figure** 6.1), in the 1800s. To study genetics, Mendel chose to work with pea plants because they had easily observable traits and a short generation time (**Figure** 6.2). For example, pea plants are either tall or short, which are easily identifiable traits. Furthermore, peas can either self pollinate or be cross-pollinated by hand, by transferring the pollen from one flower to the stigma of another. In this way, Mendel could carefully observe the results of crosses between two different types of plants. He studied the inheritance patterns for many different traits in peas, including round seeds versus wrinkled seeds, white flowers versus purple flowers, and tall plants versus short plants. Because of his work, Mendel can be considered the father of genetics.

During Mendel's time, most people believed that traits were contributed from both parents and blended together as they were passed down from generation to generation. For example, if you crossed a short plant and a tall plant, they would expect the offspring to be medium-sized plants. What Mendel observed, however, was that the offspring of this cross (called the **F1 generation,** derived from the Latin term *filius,* meaning sons and daughters) were all tall plants. Based on the blending hypothesis, the result of all tall plants was unexpected.

Next, Mendel let the F1 generation self-pollinate. He then noted that 75% of the result-

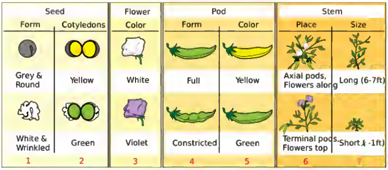

Figure 6.2: Characteristics of pea plants. (11)

ing offspring, the **F2 generation,** were tall, while 25% were short. Therefore, shortness appeared to have skipped a generation. Mendel found this same mathematical result over and over again with all the traits he studied. In all, Mendel studied seven characteristics, with almost 20,000 F2 plants analyzed. For example, purple flowers and white flowers were crossed to produce plants with only purple flowers in the F1 generation. Then after self-pollination, the F2 generation had 75% purple flowers and 25% white flowers. These results did not reflect what you would expect if the blending model of inheritance was correct.

Dominance

Mendel had to come up with a new theory of inheritance to explain his results. His explanation, the **law of segregation**, is still one of the fundamental laws of modern genetics. He proposed that each pea plant had two hereditary factors for each trait. There were two possibilities for each hereditary factor, such as short or tall. One factor is **dominant** to the other, meaning it masks the effects of the **recessive** factor. However, each parent could only pass on one of these factors to the offspring. Therefore, during the formation of **gametes,** sperm or egg, the heredity factors must separate so there is only one factor per gamete. When fertilization occurs, the offspring then have two hereditary factors.

This law explained what Mendel had seen in the F1 generation, because the two heredity factors were the short and tall factors and each individual in the F1 would have one of each factor, and as the tall factor is dominant to the short factor, all the plants appeared tall. In the F2 generation, produced by self-pollination of the F1, 25% of the offspring could have two short heredity factors, so they would appear short. 75% would have at least one tall heredity factor and will be tall.

In genetics problems the dominant factor is labeled with a capital letter (T) while the recessive factor is labeled with a lowercase letter (t). If we designate the letter T or t to represent the heritable factor, as each individual has two factors for each trait, the possible combinations are Tt, TT, and tt. Plants with TT would be tall while plants with tt would be short. Since T is dominant to t, plants that are Tt would be tall, as with the F1 generation

we described that inherited one factor from the TT tall parent and one factor from the tt short parent.

Probability and Punnett Squares

To visualize the results of a genetic cross, a **Punnett square** is helpful. An example of a Punnett square (**Figure** 6.3) that shows the results of a cross between two purple flowers that each have one dominant factor and one recessive factor (Bb). Notice how the possible factors in the sperm (B or b) are lined up the side of the square while the possible factors in the egg (B or b) are lined up across the top. The possible offspring are represented by the letters in the boxes, with one factor coming from each parent.

Notice how the Punnett square can help you predict the outcome of the crosses. Only one of the plants out of the four, or 25% of the plants, has white flowers (bb). The other 75% have purple flowers (BB, Bb) because the color purple is a dominant trait in pea plants.

Now imagine you cross one of the white flowers (bb) with a purple flower that has both a dominant and recessive factor (Bb). The only possible gamete in the white flower is the recessive (b), while the purple flower can have gametes with either dominant (B) or recessive (b). If you write out the Punnett cross, you will see that 50% of the offspring will be purple and 50% of the offspring will be white.

Keep in mind that the birth of each offspring is an independent event and has the same probability, so the traits of a previous offspring do not influence the next offspring. In the cross discussed above with two Bb flowers, each offspring has a 75% chance of being purple and a 25% chance of being white. For example, even if the first three offspring in the cross have purple flowers, it does not mean that the next plant must have white flowers. All probability tells you is that overtime the averages of many, many offspring will work out to a predicted ratio.

Table 6.1: **The Punnett Square of a white flower (bb) crossed with a purple flower (Bb)**

	b	b
B	Bb	bb
b	Bb	bb

Lesson Summary

- Gregor Mendel is considered the father of genetics, the science of studying inheritance.
- According to Mendel's law of segregation, an organism has two factors for each trait, but each gamete only contains one of these factors.

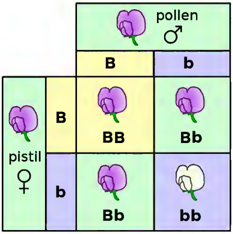

Figure 6.3: The Punnett Square of a cross between two purple flowers (Bb) (18)

- A Punnett square is useful for predicting the outcomes of crosses.

Review Questions

1. What is the term for the offspring of a cross, or the first generation?
2. What is the F2 generation?
3. Who is considered the father of genetics?
4. Why did Mendel select peas as a model for studying genetics?
5. In peas, yellow seeds (Y) are dominant over green seeds (y). If a yy plant is crossed with a YY plant, what ratio of plants in the offspring would you predict?
6. In peas, purple flowers (P) are dominant over white flowers (p). If a pp plant is crossed with a Pp plant, what ratio of plants in the offspring would you predict?
7. In guinea pigs, black fur (B) is dominant over white fur (b). If a BB guinea pig is crossed with a Bb guinea pig, what ratio of guinea pigs in the offspring would you predict?
8. In guinea pigs, smooth coat (S) is dominant over rough coat (s). If a SS guinea pig is crossed with a ss guinea pig, what ratio of guinea pigs in the offspring would you predict?
9. In humans, unattached ear lobes are dominant over attached ear lobes. If two parents have attached earlobes, what is the predicted ratio in the offspring?
10. Why would it be much easier to study genetics in pea plants than in people?

Further Reading / Supplemental Links

- http://www.mendelweb.org/MWtoc.html

- http://www.estrellamountain.edu/faculty/farabee/BIOBK/BioBookgenintro.html
- http://sonic.net/~nbs/projects/anthro201/
- http://anthro.palomar.edu/mendel/mendel_1.htm

Vocabulary

dominant Masks the expression of the recessive trait.

F1 generation The first filial generation; offspring of the P or parental generation.

F2 generation The second filial generation; offspring from the self-pollination of the F1 generation.

gametes Haploid cells involved in sexual reproduction, such egg and sperm.

genetics The study of inheritance.

punnett square Visual representation of a genetic cross that helps predict the expected ratios in the offspring.

recessive Expression is masked by the dominant factor (allele); only expressed if both factors are recessive.

Points to Consider

- Do you think all traits follow this simple pattern where one factor controls the trait?
- Can you think of other examples where Mendel's law does not seem to fit?

6.2 Lesson 6.2: Modern Genetics

Lesson Objectives

- Explain Mendel's laws with our modern understanding of chromosomes.
- Explain how codominant traits are inherited.
- Distinguish between phenotype and genotype.
- Explain how polygenic traits are inherited.

Check Your Understanding

- What is a visual representation of a genetic cross?
- What is stated in Mendel's law of segregation?

Introduction

Although Mendel laid the foundation for modern genetics, there were still a lot of questions left unanswered. How is inheritance determined for traits that do not seem to follow a simple dominant-recessive pattern? What exactly are the hereditary factors that determine traits in organisms? And how do these factors work? One of the great achievements of this past century was the discovery of DNA as the genetic material. And it is the DNA that makes up the hereditary factors that Mendel identified. By applying our modern knowledge of DNA and chromosomes, we can explain Mendel's findings and build on them.

Traits, Genes, and Alleles

Interpreting Mendel's discoveries through the eye of modern genetics, we now know that Mendel's hereditary factors are made up of DNA. Recall that our DNA is wound into chromosomes. Each of our chromosomes contains a long chain of DNA that encodes hundreds, if not thousands, of genes. Each of these genes can have slightly different versions from individual to individual. These variants of genes are called **alleles.** For example, remember that for the height gene in pea plants there are two possible alleles, the dominant allele for tallness (T) and the recessive allele for shortness (t).

Genotype and Phenotype

Genotype refers to the combination of alleles that an individual has for a certain gene. For each gene, an organism has two alleles, one on each chromosome of a homologous pair of chromosomes. The genotype is often referred to with the letter combinations that were introduced in the previous lesson, such as TT, Tt, and tt. When an organism has two of the same alleles for a specific gene, it is **homozygous** for that gene. An organism can be either homozygous dominant (TT) or homozygous recessive (tt). If an organism has two different alleles (Tt) for a certain gene, it is known as **heterozygous.** Genes have a specific place on a specific chromosome, so in the heterozygous individual these alleles are in the same location on each homologous chromosome.

Phenotype refers to the visible traits or appearance of the organism, as determined by the genotype. For example, the phenotypes of Mendel's pea plants were either tall or short, or were purple-flowered or white-flowered. Keep in mind that plants with different genotypes can have the same phenotype. For example, both a pea plant that is homozygous dominant

for the tall trait (TT) and heterozygous plant (Tt) would have the phenotype of being tall plants. The recessive phenotype only occurs if the dominant allele is absent, which is when an individual is homozygous recessive (tt).

Incomplete Dominance and Codominance

In all of Mendel's experiments, he worked with traits where a single gene controlled the trait and where one allele was always dominant to the other. Although the rules that Mendel derived from his experiments explain many inheritance patterns, the rules do not explain them all. There are in fact exceptions to Mendel's rules, and these exceptions usually have something to do with the dominant allele.

One exception to Mendel's rules is that one allele is always completely dominant over a recessive allele. Sometimes an individual has an intermediate phenotype between the two parents, as there is no dominant allele. This pattern of inheritance is called **incomplete dominance.**

An example of incomplete dominance is the color of snapdragon flowers. One of the genes for flower color in snapdragons has two alleles, one for red flowers and one for white flowers. A plant that is homozygous for the red allele will have red flowers, while a plant that is homozygous for the white allele will have white flowers. On the other hand, the heterozygote will have pink flowers (**Figure** 6.4). Neither the red nor the white allele is dominant, so the phenotype of the offspring is a blend of the two parents.

Figure 6.4: Pink snapdragons are an example of incomplete dominance. (15)

Another example of incomplete dominance is sickle cell anemia, a disease in which the hemoglobin protein is produced incorrectly and the red blood cells have a sickle shape. A person that is homozygous recessive for the sickle cell trait will have red blood cells that all

have the incorrect hemoglobin. A person who is homozygous dominant will have normal red blood cells. And because this trait has an incomplete dominance pattern of expression, a person who is heterozygous for the sickle cell trait will have some misshapen cells and some normal cells (**Figures** 6.5 and 6.6). These heterozygous individuals have a *fitness* advantage; they are resistant to severe malaria. Both the dominant and recessive alleles are expressed, so the result is a phenotype that is a combination of the recessive and dominant traits.

Figure 6.5: Sickle cell anemia causes red blood cells to become misshapen and curved (upper figure) unlike normal, rounded red blood cells (lower figure). (12)

An example of a **codominant** trait is ABO blood types (**Figure** 6.7), named for the carbohydrate attachment on the outside of the blood cell. In this case, two alleles are dominant and completely expressed (designated I^A and I^B), while one allele is recessive (i). The I^A allele encodes for red blood cells with the A antigen, while the I^B allele encodes for red blood cells with the B antigen. The recessive allele (i) doesn't encode for any antigens. An antigen is a substance that provokes an immune response, your body's defenses against disease, which will be discussed further in the *Diseases and the Body's Defenses* chapter. Therefore a person with two recessive alleles (ii) has type O blood. As no dominant (I^A and I^B) allele is present, the person cannot have type A or type B blood.

There are two possible genotypes for type A blood, homozygous (I^AI^A) and heterozygous (I^Ai), and two possible genotypes for type B blood (I^Bi and I^BI^B). If a person is heterozygous for both the I^A and I^B alleles, they will express both and have type AB blood with both antigens on each red blood cell. This pattern of inheritance is significantly different than Mendel's rules for inheritance because both alleles are expressed completely and one does not mask the other.

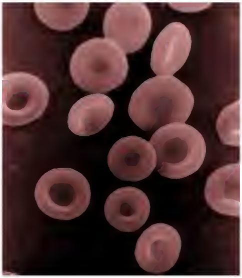

Figure 6.6: Sickle cell anemia causes red blood cells to become misshapen and curved (upper figure) unlike normal, rounded red blood cells (lower figure). (6)

Polygenic Traits and Environmental Influences

Another exception to Mendel's rules is **polygenic inheritance,** which is when a trait is controlled by more than one gene. Often these traits are in fact controlled by many genes on many chromosomes. Each dominant allele has an additive effect, so the resulting offspring can have a variety of genotypes, from no dominant alleles to several dominant alleles. In humans, some examples of polygenic traits are height and skin color. People are neither short nor tall, as was seen with the pea plants studied by Mendel, which has only one gene that encodes for height. Instead, people have a range of heights determined by many genes. Similarly, people have a wide range of skin colors. Polygenic inheritance often results in a bell shaped curve when you analyze the population (**Figure** 6.8). That means that most people are intermediate in the phenotype, such as average height, while very few people are at the extremes, such as very tall or very short.

Most polygenetic traits are partially influenced by the environment. For example, height is partially influenced by nutrition in childhood. If a child is genetically programmed to be average height but does not get a proper diet, he or she may be below average in size.

Other examples of environmentally influenced traits are mental illnesses like schizophrenia and depression. A person may be genetically predisposed to have depression, so when that person's environment contributes major stresses like losing a job or losing a close relative, the person is more likely to become depressed.

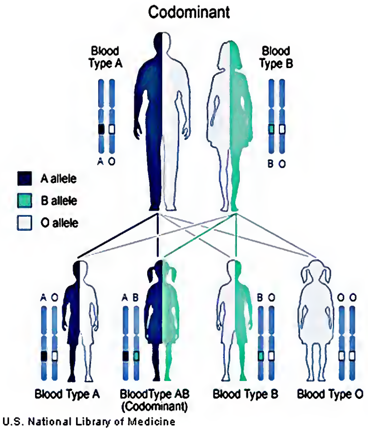

Figure 6.7: An example of codominant inheritance is ABO blood types. (4)

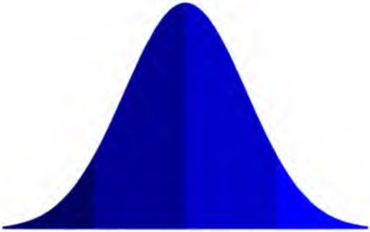

Figure 6.8: Polygenic traits tend to result in a distribution that resembles a bell-shaped curve, with few at the extremes and most in the middle. There may be 4 or 6 or more alleles involved in the phenotype. At the left extreme, individuals are completely dominant for all alleles, and at the other extreme, individuals are completely recessive for all alleles. Individuals in the middle have various combinations of recessive and dominant alleles. (7)

Linkage

Linkage refers to particular genetic position or **loci**, or alleles inherited together, suggesting that they are physically on the same chromosome, and located close together on that chromosome. A crossing-over event during prophase I of meiosis is rare between linked loci. Alleles for genes on different chromosomes are not linked; they sort independently (independent assortment) of each other during meiosis.

A gene is also said to be linked to a chromosome if it is physically located on that chromosome. For example, a gene (or loci) is said to be linked to the X-chromosome if it is physically located on the X-chromosome chromosome.

Linkage Maps

The frequency of recombination refers to the rate of crossing-over (recombination) events between two loci. This frequency can be used to estimate genetic distances between the two loci, and create a **linkage map**. In other words, the frequency can be used to estimate how close or how far apart the two loci are on the chromosome.

In the early 20$^{\text{th}}$ century, Thomas Hunt Morgan demonstrated that the amount of crossing over between linked genes differs. This led to the idea that the frequency of crossover events would indicate the distance separating genes on a chromosome. Morgan's student, Alfred Sturtevant, developed the first genetic map, also called a linkage map.

Sturtevant proposed that the farther apart linked genes were on a chromosome, the greater the chance that non-sister chromatids would cross over in the region between the genes during meiosis. By determining the number of recombinants - offspring in which a cross-over event has occurred - it is possible to determine the approximate distance between the genes. This distance is called a genetic map unit (m.u.), or a **centimorgan**, and is defined as the distance between genes for which one product of meiosis in 100 products is a recombinant. So, a recombinant frequency of 1% (1 out of 100) is equivalent to 1 m.u. Loci with a recombinant frequency of 10% would be separated by 10 m.u. The recombination frequency will be 50% when two genes are widely separated on the same chromosome or are located on different chromosomes. This is the natural result of independent assortment. Linked genes have recombination frequencies less than 50%.

Determining recombination frequencies between genes located on the same chromosome allows a linkage map to be developed. Linkage mapping is critical for identifying the location of genes that cause genetic diseases.

Lesson Summary

- Variants of genes are called alleles.
- Genotype is the combination of alleles that an individual has for a certain gene, while phenotype is the appearance caused by the expression of the genotype.
- Incomplete dominance and codominance do not fit Mendel's rules because one allele does not entirely mask the other.
- In polygenic inheritance, many genes control a trait with each dominant allele having an additive effect.

Review Questions

1. What is a variant of a gene that occurs at the same place on homologous chromosomes?
2. What is the type of allele that only affects the phenotype in the homozygous condition?
3. What type of allele masks the expression of the recessive allele and is therefore expressed in the heterozygote?
4. What is the term for the specific alleles of an individual for a particular trait?
5. What is the term for the appearance of the organism, as determined by the genotype?
6. If a organism has a certain phenotype, such as a tall pea plant, does that mean it must have the same genotype?
7. What is the term for the pattern of inheritance where an individual has an intermediate phenotype between the two parents?
8. IQ in humans varies in humans with most people having an IQ of around 100, and with a few people at the extremes, such as 50 or 150. What type of inheritance do you think this might describe?
9. A dark purple flower is crossed with a white flower of the same species and the offspring

have light purple flowers. What type of inheritance does this describe?

10. What is the inheritance pattern where both alleles are expressed?

Further Reading / Supplemental Links

- http://en.wikipedia.org/wiki/Dominant_gene
- http://en.wikipedia.org/wiki/Polygenic_inheritance
- http://staff.jccc.net/pdecell/evolution/polygen.html
- http://www.curiosityrats.com/genetics.html
- http://www.estrellamountain.edu/faculty/farabee/BIOBK/BioBookgenintro.html

Vocabulary

allele An alternative form of a gene.

co-dominance A pattern of inheritance where both alleles are equally expressed.

genotype The genetic makeup of a cell or organism, defined by certain alleles for a particular trait.

heterozygous Having identical alleles for a particular trait.

homozygous Having two different alleles for a particular trait.

incomplete dominance A pattern of inheritance where the offspring has a phenotype that is halfway between the two parents' phenotypes.

phenotype The physical appearance that is a result of the genotype.

polygenic inheritance A pattern of inheritance where the trait is controlled by many genes and each dominant allele has an additive effect.

Points to Consider

- Hypothesize about the genetic differences between males and females.
- Can you name any human genetic disorders?
- If a baby inherits an extra chromosome, what might the result be?

6.3 Lesson 6.3: Human Genetics

Lesson Objectives

- List the two types of chromosomes in the human genome.
- Predict patterns of inheritance for traits located on the sex chromosomes.
- Describe how some common human genetic disorders are inherited.
- Explain how changes in chromosomes can cause disorders in humans.

Check Your Understanding

- How many alleles does an individual have for each gene/trait?
- How do we predict the probability of traits being passed on to the next generation?
- What do we call complexes of DNA wound around proteins that pass on genetic information to the next generation of cells?

Introduction

You might know someone who was born with a genetic disorder, such as cystic fibrosis or Down syndrome. And you might have wondered how someone inherits these types of disorders. It all goes back to Mendel! Mendel's rules laid the foundation for understanding the genetics of all organisms, including humans. We can apply Mendel's rules to describe how many human traits and genetic disorders are inherited. Some disorders are caused by a recessive allele, while other disorders are caused by a single dominant allele. Therefore, we can draw a Punnett square to predict the number of offspring that may be affected with these diseases, just like we predicted for other traits in the previous lessons. Since Mendel's time, we have also expanded our knowledge of inheritance and understand that genes are located on chromosomes. Now we can now explain special inheritance patterns that don't fit Mendel's rules.

Sex-linked Inheritance

What determines if a baby is a boy or a girl? Recall that you have 23 pairs of chromosomes, one pair of which are the sex chromosomes. Everyone has two sex chromosomes, X or Y, that determine our sex. Females have two X chromosomes, while males have one Y chromosome and one X chromosome. So if a baby inherits an X from the father and an X from the mother, it will be a girl. If the father's sperm carries the Y chromosome, it will be a boy. Notice that a mother can only pass on an X chromosome, so the sex of the baby is determined by the father. The father has a 50 percent chance of passing on the Y or X chromosome, hence it is a 50 percent chance whether a child will be a boy or a girl.

One special pattern of inheritance that doesn't fit Mendel's rules is **sex-linked inheritance,** referring to the inheritance of traits which are due to genes located on the sex chromosomes. The X chromosome and Y chromosome carry many genes and some of them code for traits that have nothing to do with determining sex. Since males and females do not have the same sex chromosomes, there will be differences between the sexes in how these sex-linked traits are expressed.

One example of a sex-linked trait is red-green colorblindness. People with this type of colorblindness cannot distinguish between red and green and often see these colors as shades of brown (**Figure** 6.9). Boys are much more likely to be colorblind than girls. That's because colorblindness is a sex-linked recessive trait. Boys only have one X chromosome, so if that chromosome carries the gene for colorblindness, they will be colorblind. As girls have two X chromosomes, a girl can have one X chromosome with the colorblind gene and one X chromosome with a normal gene for color vision. Since colorblindness is recessive, the dominant normal gene will mask the recessive colorblind gene. For a girl to be colorblind, she would have to inherit two genes for colorblindness, which is very unlikely. Many sex-linked traits are inherited in a recessive manner.

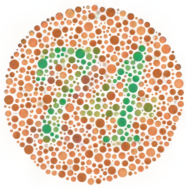

Figure 6.9: A person with red-green colorblindness would not be able to see the number. (2)

A woman can be a carrier of colorblindness, however. A **carrier** appears normal but is capable of passing on a genetic disorder to her child. Carriers for colorblindness have a heterozygous genotype of one colorblind allele and one normal allele. We can use a Punnett square to predict the probability of a carrier passing on the trait to her children. For example, if a woman who is a carrier for colorblindness has children, her boys would have a 50% chance of being colorblind and her girls have a 50% chance of being carriers.

Table 6.2:

	Xc	**X**
X	**XcX** (carrier female)	**XX** (normal female)
Y	**XcY** (colorblind male)	**XY** (normal male)

Human Genetic Disorders

Some human genetic disorders are also X-linked or Y-linked, which means the faulty gene is carried on these sex chromosomes. Other genetic disorders are carried on one of the other 22 pairs of chromosomes; these chromosomes are known as **autosomes** or autosomal chromosomes.

Some genetic disorders are caused by recessive or dominant alleles of a single gene on an autosome. These disorders would then have the same inheritance pattern as any other dominant or recessive trait. An example of an autosomal recessive genetic disorder is cystic fibrosis. Children with cystic fibrosis have excessively thick mucus in their lungs which makes it difficult for them to breathe. The inheritance of this recessive allele is the same as any other recessive allele, so a Punnett square can be used to predict the probability that two carriers of the disease will have a child with cystic fibrosis.

Table 6.3:

	F	**f**
F	**FF** (normal)	**Ff** (carrier)
f	**Ff** (carrier)	**ff** (affected)

Another recessive trait that we mentioned previously was sickle cell anemia. A person with two recessive alleles for the sickle cell trait (aa) will have sickle cell disease. In this disease the hemoglobin protein is formed incorrectly and the person's red blood cells are misshapen. A person who does not carry the sickle trait has a homozygous dominant genotype (AA). Remember the trait showed incomplete dominance, so a person who is heterozygous for the trait (Aa) would have some sickle-shaped cells and some normal red blood cells.

You can also use a simple Punnett square to predict the inheritance of a dominant autosomal disorder, like Huntington's disease. If one parent has Huntington's disease, what is the chance of passing it on to their children? If you draw the Punnett square, you will see that there is a 50 percent chance of the disorder being passed on to the children. Huntington's disease causes the brain's cells to break down, leading to muscle spasms and personality changes. Unlike most other genetic disorders, the symptoms usually do not become apparent until middle age.

Genetic diseases can also be carried on the sex-chromosomes. An example of a recessive sex-linked genetic disorder is hemophilia. A hemophiliac's blood does not clot, or clots very slowly, so he or she can easily bleed to death. As with colorblindness, males are much more likely to be hemophiliacs since the gene is on the X chromosome. Because Queen Victoria of England was a carrier of hemophilia, this disorder was once common in European royal families. Several of her grandsons were afflicted with hemophilia, but none of her granddaughters were affected by the disease, although they were often carriers. Because at the time medical care was very primitive, often hemophiliacs bled to death, and usually at a young age. Queen Victoria's grandson Frederick died at age 3, and her grandson Waldemar died at age 11 (**Figure** 6.10).

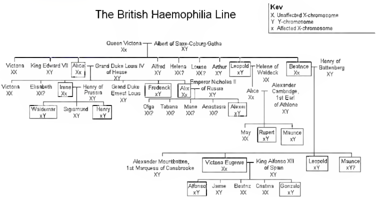

Figure 6.10: A pedigree chart shows all the phenotypes for a particular trait in the family. This pedigree chart traces back the occurrence of hemophilia in the British royal family. Those individuals with boxes around them are either female carriers of the trait or males inflicted with the trait. (13)

Many genetic disorders are recessive, meaning that an individual must be homozygous for the recessive allele to be affected. Sometimes these disorders are lethal (deadly), however,

heterozygous individuals (unaffected individuals with one dominant allele and one recessive allele) survive. This allows the allele that causes the genetic disorder to be maintained in a population's **gene pool.** A gene pool is the complete set of unique alleles in a species or population. A mutation is a change in the DNA sequence. New mutations are constantly being generated in a gene pool.

Pedigree Analysis

A **pedigree** is a chart which shows the inheritance of a trait over several generations. A pedigree is commonly created for families, and it outlines the inheritance patterns of genetic disorders. **Figure** 6.11 shows a pedigree depicting recessive inheritance of a disorder through three generations. Scientists can tell the genetics of inheritance from studying a pedigree, such as whether the trait is sex-linked (on the X or Y chromosome) or autosomal (on a chromosome that does not determine sex), whether the trait is inherited in a dominant or recessive fashion, and possibly whether individuals with the trait are heterozygous or homozygous.

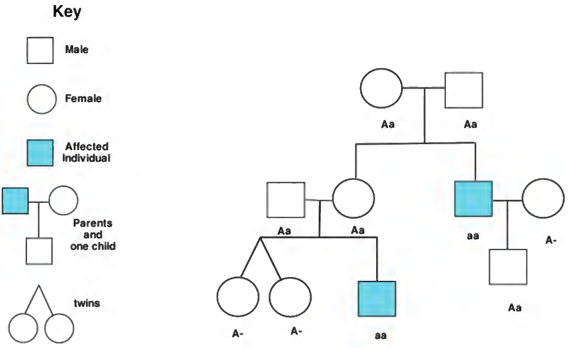

Figure 6.11: In a pedigree, squares symbolize males, and circles represent females. A horizontal line joining a male and female indicates that the couple had offspring. Vertical lines indicate offspring which are listed left to right, in order of birth. Shading of the circle or square indicates an individual who has the trait being traced. The inheritance of the recessive trait is being traced. A is the dominant allele and a is recessive. (1)

Chromosomal Disorders

Some children are born with genetic defects that are not carried by a single gene. Instead, an error in a larger part of the chromosome or even in an entire chromosome causes the disorder. Usually the error happens when the egg or sperm is forming. One common example is Down syndrome (**Figure** 6.12). Children with Down syndrome are mentally disabled and have collection of recognizable physical deformities. Down syndrome occurs when a baby receives an extra chromosome from one of his or her parents. Usually a child would have one chromosome 21 from your mother and one chromosome 21 from your father. But in an individual with Down syndrome, there are three copies of chromosome 21. Down syndrome is also known as trisomy 21.

Figure 6.12: A child with Down syndrome. (16)

Another example of a chromosomal disorder is Klinefelter syndrome, in which a male inherits an extra "X" chromosome. These individuals have underdeveloped sex organs and elongated limbs, and have difficulty learning new things. Outside of chromosome 21 and the sex chromosomes, most embryos with extra chromosomes do not even make it to the fetal stage. Because chromosomes carry many, many genes, a disruption of a chromosome potentially causes severe problems with development of the fetus.

Besides diseases caused by duplicated chromosomes, other chromosomal disorders occur when the structure of a chromosome is disrupted. For example, if a tiny portion of chromosome 5 is missing, the individual will have cri du chat (cat's cry) syndrome. These individuals have

misshapen facial features and the infant's cry resembles a cat's cry.

Lesson Summary

- Some human traits are controlled by genes on the sex chromosomes.
- Human genetic disorders can be inherited through recessive or dominant alleles, and they can be located on the sex chromosomes or autosomes.
- Changes in chromosome number can lead to disorders like Down syndrome.

Review Questions

1. How many chromosomes do you have in each cell of your body?
2. How is Down syndrome inherited?
3. A son cannot inherit colorblindness from his father. Why not?
4. One parent is a carrier of the cystic fibrosis gene, while the other parent does not carry the allele. Can their child have cystic fibrosis?

Further Reading / Supplemental Links

- http://www.articlesbase.com/health-articles/what-is-haemophilia-412305.html
- http://www.scribd.com/doc/1018249/lectureChromsomes-and-Human-Genetics-Guevedoces
- http://geneticdisorderinfo.wikispaces.com/
- http://learn.genetics.utah.edu/units/disorders/karyotype/karyotype.cfm
- http://www.hhmi.org/biointeractive/vlabs/cardiology/index.html
- http://en.wikipedia.org/

Vocabulary

autosomes The chromosome other than the sex chromosomes.

carrier A person who is heterozygous for a recessive genetic disorder; the person does not have the disease but can pass the disease allele to the next generation.

sex-linked trait A trait that is due to a gene located on a sex chromosome, usually the X-chromosome.

Points to Consider

- Human cloning is illegal in many countries. Do you agree with these restrictions?

- Why would it be helpful to know all the genes that make up human DNA?
- It may be possible in the future to obtain the sequence of all your genes. Would you want to take advantage of this opportunity? Why or why not?

6.4 Lesson 6.4: Genetic Advances

Lesson Objectives

- Explain how clones are made.
- Explain how vectors are made.
- Explain what sequencing a genome tells us.
- Describe how gene therapy works.

Check Your Understanding

- What part of the cell contains the genetic material?
- What are the base pairing rules for DNA?

Introduction

Since Mendel's time, there have been rapid advances in the understanding of genetics. As scientists understand better how DNA works, they can develop technologies that allow us to reveal the genetic secrets encoded in our DNA and even alter an organism's DNA. Genetic engineering (or *biotechnology* or *DNA technology*) has helped us better understand and predict the inheritance of genetic diseases, produce new medicines, and even produce new food products. DNA technology has also made an impact on fighting crime. Because DNA is unique to an individual, the DNA in just a few hairs at a crime scene can help identify a criminal. This technology, known as DNA fingerprinting, has also helped innocent imprisoned people to appeal their case and clear their names. DNA technology has revolutionized not only criminal justice, but also many other aspects of our lives.

Recombinant DNA

Recombinant DNA is the combination of DNA from two different sources. It is useful in gene cloning and in identifying the function of a gene, as well as producing useful proteins. Human insulin for treating diabetes has been produced through recombinant DNA methods. In this process, a gene of interest (or piece of DNA of interest) is placed into a host cell, such as a bacterium, so the gene can be copied (and cloned) and the protein that results from that gene can be produced.

To place the gene of interest into a host cell, a **vector,** or carrier molecule, is needed to the carry foreign DNA into the host cell. Bacteria have small accessory rings of DNA in the cytoplasm, called **plasmids**. When putting foreign DNA into a bacterium (a host cell), the plasmids are often used as a vector. Viruses can also be used as vectors.

The first step of making recombinant DNA involves a **restriction enzyme** that cuts the vector and the foreign (exogenous) DNA. Restriction enzymes cut DNA at specific sequences, such as GAATTC as shown in **Figure** 6.13 . There are more than 3,000 known restriction enzymes, most cutting the DNA at a unique sequence. This reaction results in the plasmid opening up a gap with "sticky ends," which can attach with the complimentary base pairs on the sticky ends of the foreign DNA. Then the enzyme **DNA ligase** seals the foreign DNA in its new place inside the plasmid. These altered plasmids are introduced back into the bacteria, a process called **transformation** (**Figure** 6.14). The bacteria will express the foreign gene.

Figure 6.13: Restriction enzymes cut DNA at specific sequences, in this example the sequence "GAATTC." The enzyme cuts between the G and A on each strand, producing overhanging "sticky ends." (5)

One application of recombinant DNA technology is producing the protein insulin, which is needed to treat diabetes. Previously, insulin had been extracted from the pancreases of animals. Through recombinant DNA technology, bacteria were created that carry the human gene which codes for the production of insulin. These bacteria become tiny factories that produce this protein. A step-by-step depiction of the cloning of the insulin gene is shown below in (**Figure** 6.15).

Cloning

Cloning is the process of creating an exact replica of an organism. The clone's DNA is exactly the same as the parent's DNA. Bacteria and plants have long been able to clone themselves through processes of asexual reproduction. In animals, however, cloning does not happen naturally.

Animals can now be cloned in a laboratory, however. In 1997, a sheep named Dolly was the first mammal ever to be successfully cloned. The process of producing an animal like Dolly

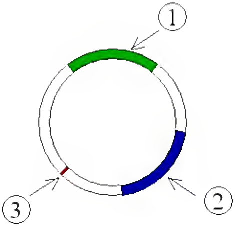

Figure 6.14: This image shows a line drawing of a plasmid. The plasmid is drawn as two concentric circles that are very close together, with two large segments and one small segment depicted. The two large segments (1 and 2) indicate antibiotic resistances usually used in a screening procedure, and the small segment (3) indicates an origin of replication. The resulting DNA is a recombinant DNA molecule. (3)

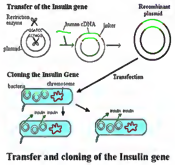

Figure 6.15: A step-by-step depiction of the cloning of the insulin gene. The plasmid is opened up with restriction enzymes and the gene of interest (human cDNA) is inserted into the plasmid with complementary linkers, producing the recombinant plasmid. The plasmid is transfected into bacterial cells, where the human protein is produced. (17)

starts with a single cell from the animal that is going to be cloned. In the case of Dolly, cells from the mammary glands were taken from the adult that was to be cloned. These cells are called **somatic,** meaning they come from the body and are not gametes like sperm or egg. Remember that somatic cells have a diploid number of chromosomes. Next, the nucleus was removed from this cell. The nucleus was placed in a donor egg that had already had the nucleus removed. The new cell then divided after the stimulation of an electric shock, and development proceeded normally just as if the embryo had formed naturally. The resulting embryo was implanted in a surrogate mother sheep, where it continued its development. This process is shown in **Figure** 6.16.

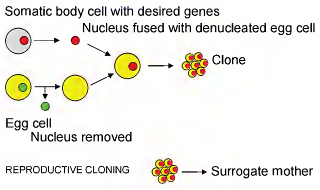

Figure 6.16: To clone an animal, a nucleus from the animal's cells are fused with an egg cell (in which the nucleus has been removed) from a donor. (14)

Cloning is not always successful, though. Most of the time, this cloning process does not result in a healthy adult animal. The process has to be repeated many times until it works. In fact, 277 tries were needed to produce Dolly. This high failure rate is one reason that human cloning is banned in the United States. In order to produce a cloned human, many attempts would result in the surrogate mothers experiencing miscarriages, stillbirths, or deformities in the infant. There are also many additional ethical considerations related to human cloning.

Human Genome Project

A person's genome is all of his or her genetic information; in other words, the human genome is all the information that makes us human. The **Human Genome Project** (**Figure** 6.17) was an international effort to sequence all 3 billion bases that make up our DNA and to identify within this code the over 20,000 human genes. Scientists also completed a chromosome map, identifying where the genes are located on each of the chromosomes. The Human Genome Project was completed in 2003. Though the Human Genome Project is finished, analysis of the data will continue for many years.

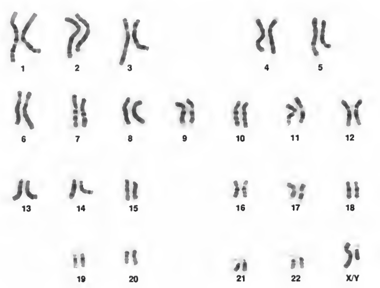

Figure 6.17: To complete the Human Genome Project, all 23 pairs of chromosomes in the human body were sequenced. Each chromosomes contains thousands of genes. This is a karyotype, a visual representation of an individual's chromosomes lined up by size. (8)

There are many exciting applications of the Human Genome Project. The genetic basis for many diseases can be more easily determined, and now there are tests for over 1,000 genetic disorders. The National Institutes of Health, the United States government's premiere biomedical research community, is also looking for ways to reduce the costs of sequencing so that people can have a map of their individual genome. Although some disorders are caused by a single gene, many other illnesses are caused by a combination of several genes and a person's lifestyle. Analysis of your own genome could determine if you are at risk for specific diseases. Knowing you might be genetically prone to a certain disease would allow you to better seek preventive lifestyle changes and medical screenings.

A **genetic map** shows the location (or **loci**) of a gene on a chromosome. Genetic maps are important tools to help researchers understand genes and genetic diseases. Knowing where genes are in relation to other genes and knowing the order of genes on a chromosome is an important aspect of human genetics. The frequency of recombination (crossing-over during prophase I of meiosis) allows geneticists to estimate the distance between loci. Because crossing-over occurs relatively rarely at any location along the chromosome, the frequency of recombination between two locations depends on their distance. The farther apart genes are on the same chromosome, the more likely there is to be a cross-over event between them. The likelihood of a cross-over event between two closely located genes (said to be **linked**) is small.

Gene Therapy

Gene therapy is the insertion of genes into a person's cells to cure a genetic disorder. There are two main types of gene therapy; one done inside the body and one done outside the body. In *ex vivo* gene therapy, done outside the body, cells are removed from the patient and the proper gene is inserted using a virus as a vector. Then the modified cells are placed back into the patient. One of the first uses of this type of gene therapy was in the treatment of a young girl with a rare genetic disease, Adenosine deaminase deficiency, or ADA deficiency. People with this disorder are missing the ADA enzyme, which breaks down a toxin called deoxyadenosine. If the toxin is not broken down, it accumulates and destroys immune cells. As a result, individuals with ADA deficiency do not have a healthy immune system to fight off infections. In the gene therapy treatment for this disorder, bone marrow stem cells were taken from the girl's body and the missing gene was inserted in these cells outside the body. Then the modified cells were put back into her bloodstream. This treatment proved sufficient to restore the function of her immune system, but only with continual repeated treatments.

During *in vivo* gene therapy, done inside the body, the vector with the gene of interest is introduced directly into the patient and taken up by the patient's cells. The vector is inserted where the gene product is needed. For example, cystic fibrosis gene therapy is targeted at the respiratory system, so a solution with the vector can be sprayed into the patient's nose. Recently *in vivo* gene therapy was also used to partially restore the vision of three young adults with a rare type of retinal disease that is congenital, meaning present at birth.

Biotechnology in Medicine and Agriculture

There are many applications of genetic information, including applications in medicine and agriculture. These applications show daily the significance of biotechnology, and the impact biotechnology has on our society.

Medicine

As mentioned above, one application of recombinant DNA technology is producing the protein insulin. Using biotechnological techniques, the specific gene sequence that codes for human insulin was introduced into the bacteria *E. coli*. The transformed gene altered the genetic makeup of the bacterial cells, such that in a 24 hour period, billions of *E. coli* containing the human insulin gene resulted, producing human insulin to be administered to patients. Recombinant DNA technology has allowed mass quantities of insulin to be produced, treating the growing population that relies on this protein.

Though the production of human insulin by recombinant DNA procedures is an extremely significant event, many other aspects of DNA technology are beginning to become reality. In medicine, modern biotechnology provides significant applications in such areas as pharma-

cogenomics, genetic testing (and prenatal diagnosis), and gene therapy. These applications use our knowledge of biology to improve our health and our lives. Many of these medical applications are based on the findings of the Human Genome Project.

Agriculture

Biotechnology has also led scientists to develop useful applications in agriculture and food science. These include the development of **transgenic crops** - the placement of genes into plants to give the crop a beneficial trait. Benefits include:

- Improved yield from crops.
- Reduced vulnerability of crops to environmental stresses.
- Increased nutritional qualities of food crops.
- Improved taste, texture or appearance of food.
- Reduced dependence on fertilizers, pesticides and other agrochemicals.

Crops are obviously dependent on environmental conditions. Drought can destroy crop yields, as can too much rain or floods. But what if crops could be developed to withstand these harsh conditions? Biotechnology will allow the development of crops containing genes that will enable them to withstand harsh conditions. For example, drought and excessively salty soil are two significant factors affecting crop productivity. But there are crops that can withstand these harsh conditions. Why? Probably because of that plant's genetics. So scientists are studying plants that can cope with these extreme conditions, trying to identify and isolate the genes that control these beneficial traits. The genes could then be transferred into more desirable crops, with the hope of producing the same phenotypes in those crops.

Thale cress (**Figure** 6.18), a species of *Arabidopsis (Arabidopsis thaliana)*, is a tiny weed that is often used for plant research because it is very easy to grow and its DNA has been extensively characterized. Scientists have identified a gene from this plant, At-DBF2, that gives the plant resistance to some environmental stresses. When this gene is inserted into tomato and tobacco cells, the cells were able to withstand environmental stresses like salt, drought, cold and heat far better than ordinary cells. If these preliminary results prove successful in larger trials, then At-DBF2 genes could help in engineering crops that can better withstand harsh environments. Researchers have also created transgenic rice plants that are resistant to a rice virus. In Africa, this virus destroys much of the rice crops and makes the surviving plants more susceptible to fungal infections.

Lesson Summary

- Using recombinant DNA technology, a foreign gene can be inserted into an organism's DNA.

Figure 6.18: Thale cress. (10)

- Cloning of mammals is still being perfected, but several cloned animals have been created by implanting the nucleus of a somatic cell into a cell in which the nucleus has been removed.
- The Human Genome Project produced a genetic map of all the human chromosomes and determined the sequence of every base pair in our DNA.
- Gene therapy involves treating an illness caused by a defective gene through the use of a vector to integrate a normal copy of the gene into the patient.

Review Questions

1. What is the enzyme used to cut DNA at specific points?
2. What is the term for all the genetic information of the human species?
3. What are the rings of accessory DNA in bacteria that are often used as a vector in genetic engineering?
4. What is the term for producing identical copies of an organism?
5. Can gene therapy cure a disease caused by a virus?
6. What is the vehicle used to introduce foreign DNA into an organism?
7. What is one disease that genetic therapy can help treat?
8. What supplies the cytoplasm of the clone's cells during the cloning of an organism?
9. What is one application of recombinant DNA technology?
10. Is gene therapy for ADA deficiency a permanent fix?

Further Reading / Supplemental Links

- http://www.ornl.gov/sci/techresources/Human_Genome/home.shtml
- http://history.nih.gov/exhibits/genetics/sect4.htm
- http://learn.genetics.utah.edu/units/disorders/whataregd/ada/
- http://www.lifesitenews.com/ldn/2007/nov/07112003.html
- http://www.le.ac.uk/ge/genie/vgec/sc/genomics.html
- http://en.wikipedia.org/wiki/Recombinant_DNA
- http://www.hhmi.org/biointeractive/vlabs/transgenic_fly/index.html
- http://www.groundreport.com/World/Scientists-to-clone-rhino

Vocabulary

cloning Creating an identical copy of an individual with the same genes.

DNA ligase Enzyme that joins DNA fragments together.

gene therapy Treatment that provides a new gene to replace a defective gene; potentially "cures" a genetic disease.

human genome project International effort to sequence all the base pairs in human DNA.

plasmid An accessory circle of DNA in bacteria.

recombinant DNA DNA formed bu the combination of DNA from two different sources, such as placing a human gene into a bacterial plasmid.

somatic cell A body cell; not a gamete.

transformation The process by which bacteria pick up foreign DNA and incorporate it in their genome.

vector A vehicle, such as a plasmid, used to transfer foreign DNA into an organism.

Points to Consider

Next we begin to discuss evolution, the change in species over time.

- Fossils provide evidence of evolution, but what is a fossil?
- If two animals are similar in structure, would you guess they are closely related? Why or why not?

Image Sources

(1) Rozzychan. http://en.wikipedia.org/wiki/Image:PedigreechartB.png. CC-BY-SA 2.5.

(2) http://en.wikipedia.org/wiki/Image:Ishihara_9.png. Public Domain.

(3) http://commons.wikimedia.org/wiki/Image:Example_plasmid.png. GNU-FDL.

(4) NIH. http://commons.wikimedia.org/wiki/Image:Codominant.jpg. Public Domain.

(5) http://commons.wikimedia.org/wiki/Image:Restriction_enzyme.jpg. Public Domain.

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(9) *Gregor Mendel*. Public Domain.

(10) *Thale cress.*. GNU-FDL.

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(16) *A child with Down syndrome.*. CC-BY 2.0.

(17) Dr. Kathleen A. Marrs. http://images.google.com/imgres?imgurl=http://www.madison.k12.ky.us/ms/departments/science/whatisbiology/assests/pic17b.gif.

(18) *The Punnett Square of a cross between two purple flowers (Bb)*. GNU-FDL.

Chapter 7

Evolution

7.1 Lesson 7.1: Evolution by Natural Selection

Lesson Objectives

- Understand that inherited traits, such as the basic color of skin or a person's bone structure, are passed on to future generations.
- Understand that acquired traits, such as a tan or being good at soccer, are not passed on to future generations (they are not inherited).
- Understand that evolution is change of an inherited trait in a population over many generations, such as the change of the color of moths living on an island over many generations.
- Understand that natural selection means that organisms with traits that help them survive in their environment are more likely to survive than organisms without that beneficial trait.
- Understand how evolution explains:
  - Why populations change.
  - Why there are so many different kinds of organisms on Earth.
  - Why some organisms that look alike only distantly related.
  - Why some organisms that look very different actually closely related?
- Know that both Darwin and Wallace developed the theory of evolution by natural selection at the same time.

Check Your Understanding

- What does the word evolution refer to when used in day to day conversations?
- What does biological evolution mean?

- Who primarily proposed the theory of evolution by natural selection?

Introduction

Biological evolution is change in species over time. The idea of evolution was proposed by many people before Charles Darwin (**Figure** 7.1) began collecting evidence for the idea. Scientists for hundreds of years had hypothesized that species change over time. But it was not until Darwin published his research and detailed analysis that the idea of evolution started to gain widespread acceptance. Darwin's theory of evolution by natural selection brings all fields of biology together and illuminates nearly every aspect of biology. As one famous biologist said, "Nothing in biology makes sense except in the light of evolution."

Figure 7.1: Charles Darwin was one of the most influential scientists who has ever lived. Darwin introduced the world to the theory of evolution by natural selection, which laid the foundation for how we understand the living world today. (18)

Evolution by natural selection explains:

- The tremendous variety of organisms on Earth.
- Why some organisms that resemble each other are distantly related.
- Why some organisms that do not resemble each other are closely related.

There are three parts to Darwin's Theory of Evolution by Natural Selection.

1. Evolution, which is change in species over multiple generations (**Figure** 7.2).
2. Natural selection, in which individuals of a population that are most likely to survive and reproduce are also most likely to pass on traits that have a genetic basis to any offspring.
3. Adaptation, which are traits that help a plant or animal survive and reproduce in a particular environment. Adaptations are the result of natural selection. For example, light-colored moths on dark trees might be easier for birds to see and catch than dark moths on dark-colored trees. If the moths' color has a genetic basis, then after many generations of birds catching more light moths than dark moths, the population of moths will consist mostly of dark moths.

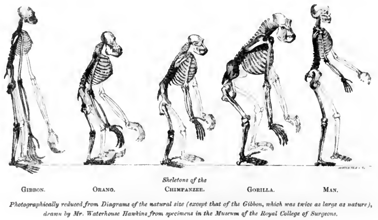


Figure 7.2: Humans and the other apes in this drawing all evolved from a common apelike ancestor. (2)

In everyday English, "evolution" simply means to "change" or a "stepwise change from simple to complex." In biology, evolution means change in the inherited traits of a group of organisms over multiple generations (**Figure** 7.3). Biological evolution has changed biologists' understanding of all life on Earth.

Darwin's Observations

Most people in the world did not become aware of the theory of evolution until 1859, when Charles Darwin published his book *On the Origin of Species by Means of Natural Selection*. This book described the observations and evidence that he collected over 20 years of intensive research, beginning with a five-year voyage around the world on a British research ship, the *HMS Beagle*. During this five-year voyage (**Figure** 7.4), Darwin was able to make observations about plants and animals spread around the world, and to collect specimens to study when he returned to England. Each time the Beagle stopped at a port to do some

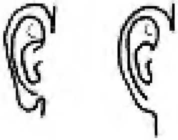


Figure 7.3: Human earlobes may be free or attached. You inherited the particular shape of your earlobes from your parents. Inherited traits are influenced by genes, which are passed on to offspring and future generations. Your summer tan is not passed on to your offspring. Natural selection only operates on traits like earlobe shape that have a genetic basis, not on traits like a summer tan that are "acquired." (4)

trading, Darwin went on land to explore and look for the local plants, animals, and fossils. One of the most important things Darwin did was to keep a diary. He took extremely detailed notes and drawings about everything he saw as well as his thoughts.

Figure 7.4: Charles Darwin's famous five year voyage was aboard the *HMS Beagle* from 1831-1836. (7)

The Galápagos Islands

The around the world voyage of the *HMS Beagle* was mostly to map the coastline of South America. Darwin's best known discoveries were made on the Galápagos Islands (**Figure** 7.5), a group of 16 volcanic islands near the equator about 600 miles from the west coast of South America. Darwin was able to spend months on foot exploring the islands. Darwin's Theory of Evolution by Natural Selection was a result of his observations and over 20 years

of examining the specimens he had collected and sent back to England, many of which came from these islands.

Figure 7.5: The Galápagos Islands are a group of 16 volcanic islands 972 km off the west coast of South America. The islands are famous for their many species found nowhere else. (35)

Darwin was amazed by the array of life he saw on the Galápagos Islands. He saw animals unlike anything he had ever seen before. Darwin was struck by how the same kind of animal differed from one island to another. For example, the iguanas (large lizards) differed between islands (**Figure** 7.6). The members of one iguana species spent much of their time swimming and diving underwater for seaweed, while those of another iguana species lived on land and ate cactus. In England, he was accustomed to watching cormorants fly, so he was surprised to find flightless cormorants on the islands alongside flying cormorants.

Giant Tortoises

Giant tortoises (**Figure** 7.7), large enough for two men to ride on, plodded across the islands and foraged on super tough leaves. Some of the tortoise species were found on only one island. Darwin was fascinated by the number of ways that organisms were well-suited to their environments. Even the tortoise shells were specially adapted to the conditions. Tortoises that ate plants near the ground had rounded shells, while the tortoises that stretched their necks to reach plants higher in shrubs had shells that bent upwards, allowing them to stretch their necks upward (**Figure** 7.8).

Figure 7.6: The Galápagos land iguanas are among the signature animals of the Galápagos Islands. (32)

Figure 7.7: The name "Galápagos" means "giant tortoise." When Darwin arrived on the Galápagos Islands, he was amazed by the size and variety of shapes of these animals. The giant tortoise is a unique animal found only in the Galápagos Islands. There only about 200 tortoises remaining on these islands. (30)

Figure 7.8: This tortoise is able to reach leaves high in shrubs with its long neck and curved shell. (12)

Darwin's Finches

The most extensively studied animals on the Galápagos are the finch species (birds) (**Figure** 7.9). When Darwin first observed the finches on the islands, he did not even realize they were all finches. But when he studied them further, he realized they were all the same type of bird, and that each island had its own distinct species of finch. The birds on different islands had many similarities, but their beaks differed in size and shape.

In his diary, Darwin pointed out how each animal is well-suited for its particular environment. The shape of the finch's beaks on each island were well-matched with the seeds available on their particular island, but not the seeds on other islands. A larger and stronger beak was needed to break open large seeds and a small beak was needed to feed on some of the smallest seeds.

Darwin also noticed how different species were distributed around the world. The finch, tortoise and other species found on the Galápagos Islands were similar to species on South America, the nearest continent. Yet they also differed. Likewise, species he saw on islands *near* Africa were similar to, but different from species *on* Africa.

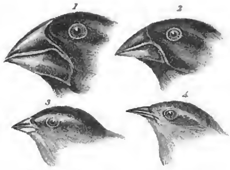


Figure 7.9: Four of Darwin's finch species from the Galápagos Islands. The birds came from the same finch ancestor. They evolved as they adapted to different food resources on different islands. The first bird uses its large beak to crack open and eat large seeds. Bird #3 is able to pull small seeds out of small spaces. (31)

Return to England

When Darwin returned to England five years later, he did not rush to announce his discoveries. Unlike other naturalists before him, Darwin did not want to present any ideas unless he had strong evidence supporting them. Instead, once Darwin returned to England, he spent over twenty years examining specimens, talking with other scientists and collecting more information before he presented his theories. Darwin's observations eventually resulted in the Theory of Evolution by Natural Selection. His now famous book, *The Origin of Species* is a diary of his explorations and discussion on how he interpreted his observations (**Figure** 7.10).

Other Influences on Darwin

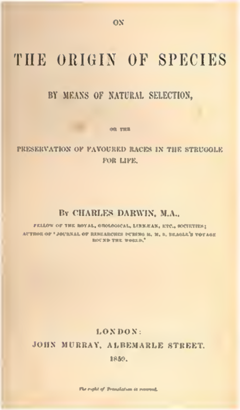
How did Darwin come up with his theories? Some of Darwin's idea conflicted with widely held beliefs, included those from religious leaders, such as:

- All organisms never change and never go extinct, they are fixed.
- The world is only about 6,000 years old.

It was because of these widely held beliefs that delayed Darwin from presenting his findings.

Charles Darwin was influenced by the ideas from several people.

Before his voyage on the Beagle:



ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE.

BY CHARLES DARWIN, M.A.,

FELLOW OF THE ROYAL, GEOLOGICAL, LINNÆAN, ETC., SOCIETIES;
AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE ROUND THE WORLD.'

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

The right of Translation is reserved.

Figure 7.10: Charles Darwin presented the Theory of Evolution by Natural Selection in this book. The theories were based on evidence he collected and tested. (29)

1. Jean-Baptiste Lamarck proposed the idea that evolution occurs. However, Darwin differed with Lamarck on several other points. Lamarck proposed that traits acquired during one's lifetime could be passed to the next generation.
2. Darwin's grandfather, Erasmus Darwin, wrote a book called *Zoonomia*. Charles Darwin was influenced by many of his grandfather's ideas including his descriptions of how species change (evolve) through artificial selection. During artificial selection, people choose specific traits to pass to the next generation, such as with horse or dog breeding (See below).
3. Charles Lyell, a well-known geologist and one of Darwin's instructors. Darwin learned about geology, paleontology and the changing Earth from Lyell. These findings suggested the Earth must be much older than 6,000 years.
4. Thomas Malthus: Darwin's ideas of natural selection were inspired by reading an essay by Thomas Malthus, an economist who suggested that humans could overpopulate and potentially exhaust food supplies. Darwin thought this must be especially true for animals, as they have a tendency to have more offspring than people have. There would therefore be a competition for survival.
5. Charles Darwin came upon some of his ideas about natural selection and adaptations from reading about artificial selection and breeding dogs. All dogs, from Chihuahuas to St. Bernards are part of the same species as wolves (*Canis lupus*). Humans created the different breeds of dogs by selecting dogs with specific traits to breed together. For example, greyhounds were created by selecting the fastest runners and breeding them together (**Figure** 7.11).
6. After the Voyage of the Beagle: Alfred Russel Wallace, another naturalist, also developed a theory of evolution by natural selection. Alfred Wallace toured South American and came up with a very similar theory of evolution by natural selection at the same time that Darwin did. Darwin and Wallace presented their theories and evidence in public together. Because of the vastness of Darwin's data, and his book, he is mostly credited and associated with this theory.

Natural Selection and Adaptation

The Theory of Evolution by Natural Selection means that the inherited traits of a population change over time through natural selection. Inherited traits are features that are passed from one generation to the next. For example, your eye color is an inherited trait (you inherited from your parents). Acquired traits are features such strong muscles from working out.

Natural selection happens when some organisms have traits that make them better suited (they have better accommodation) to live in a certain environment than others. They are more likely to survive, reproduce and pass their traits on to future generations than those without the special traits. The process of natural selection helps us understand how organisms appear to be so well suited or adapted to their environments. Every plant and animal depends on its traits to survive. Survival may include getting food, building homes, and

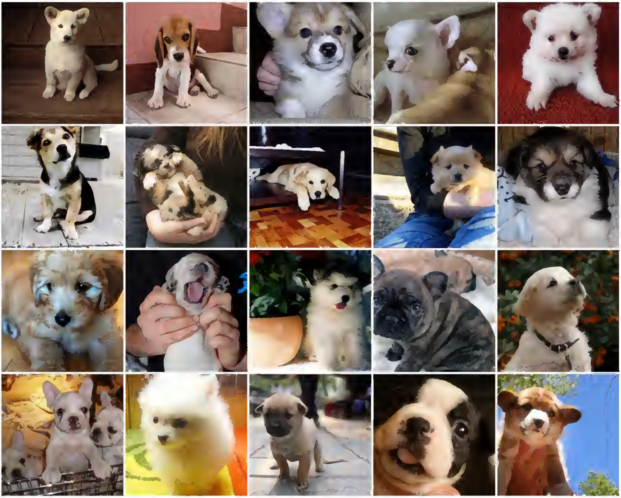


Figure 7.11: Darwin's grandfather had a big influence on Darwin's ideas by introducing him to artificial selection of dogs and horses. Humans have created hundreds of dog breeds by selecting which dogs to breed based on certain features, such as size, coloration, speed, or facial features. (23)

attracting mates. Most of these traits have been changed through natural selection so they allow a plant, animal, or bacteria to survive and reproduce relatively well in their environments. These traits are called adaptations. As environments have changed considerably over time, organisms must constantly adapt to those environments. It is the great diversity of species that increases the chance that at least some organisms adapt and survive any major changes in the environment.

Imagine how in winter dark fur makes a rabbit easy for fox to spot and catch in the snow. Natural selection suggests that white-fur is an advantageous trait that improves the chance that a rabbit will survive, reproduce and pass the trait of white fur on to future generations (**Figure** 7.12). Dark fur rabbits will become uncommon.

Figure 7.12: In winter, the fur of arctic hares turns white. The camouflage may make it more difficult for fox and other predators to locate hares against the white snow. (27)

Polygenic Inheritance and Natural Selection

But natural selection leading to evolution does not just select for certain individuals, it selects for groups. More than one individual must adapt to the environment to maintain a population. Natural selection determines which groups of organisms survive, based on their traits, and which do not, that is, natural selection determines the differential survival of groups of organisms.

Although some traits are determined by a single gene, many are influenced by more than one gene (polygenic). The result of polygenic inheritance is a continuous spectrum of phenotypic values which often show a bell curve pattern of variation.

Given this pattern of phenotypic variability, natural selection can take three forms (**Figure** 7.14). We will use the hypothetical color distribution in this figure to illustrate the three

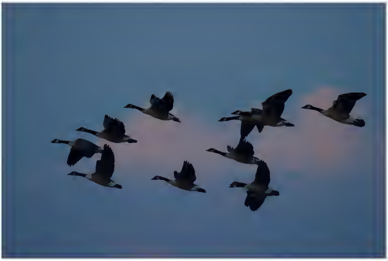


Figure 7.13: Natural selection determines the survival of groups of organisms. Flight as shown in these geese is an evolutionary step that probably aided in the survival of many birds. (15)

types of selection. **Directional selection** shifts the frequency curve away from the average by favoring individuals with an extreme form of the variation. The curve would still be bell-shaped, but it would have shifted to the left or right, in the direction of the lighter or darker alleles. **Stabilizing selection** selects for a group of phenotypically average individuals, with individuals with either extreme phenotype selected against. **Disruptive selection** selects for groups of individuals with extreme phenotypes, selecting against individuals with the average phenotype.

Lesson Summary

- Evolution is change in species over multiple generations.
- Natural selection is how evolution occurs.
- Adaptations are the result of natural selection.
- Charles Darwin is credited with developing the Theory of Evolution by Natural Selection
- Darwin collected much of his evidence on a five year voyage around the world, with much of his data collected on the Galápagos Islands.
- The work of many others contributed to Darwin's theory.

Review Questions

1. What is biological evolution?

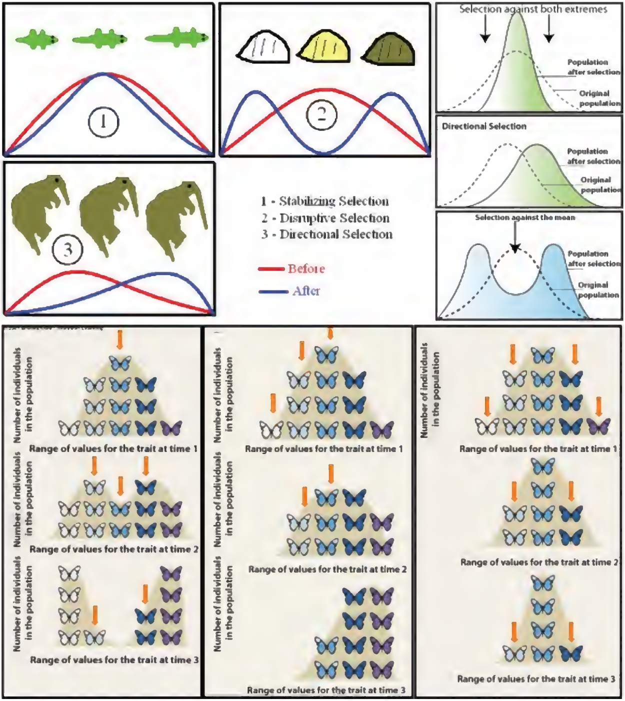


Figure 7.14: Three types of selection can alter allele frequencies, causing microevolution. The effect of stabilizing selection (1) is to select for the average phenotype, reducing variation. Disruptive selection (2) results in two different populations, which may eventually be isolated from one another. Directional selection (3) selects for a group of individuals with a single characteristic. (20)

2. What is natural selection?
3. What is adaptation?
4. What is the difference between an inherited trait and an acquired trait?
5. What was the name of the ship that Darwin traveled on?
6. What is the name of the islands where Darwin studied evolution?
7. A giraffe's long neck allows the giraffe to eat leaves from high in the tree. This is an example of an __________________.
8. Who proposed a theory of evolution by natural selection that was similar to Darwin's theory?

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Vocabulary

acquired trait A feature that an organism gets during its lifetime in response to the environment (not from genes); not passed on to future generations through genes.

adaptation Beneficial traits that help an organism survive in its environment. Organisms with beneficial traits are more likely to survive, reproduce and pass their traits on to future generations than those without the special traits. These traits are called adaptations.

artificial selection Selection in which people choose specific traits to pass to the next generation, such as with horse or dog breeding.

evolution A process in which something passes by degrees to a different stage, such as a living organism turning into a more advanced or mature organism; the change of the inherited traits of a group of organisms over many generations.

evolution by natural selection The changes in the inherited traits of a population from one generation to the next; due to a process where organisms that are best suited to their environments have greater survival and reproductive success.

Galápagos Islands A group of islands in the Pacific off South America; owned by Ecuador; known for unusual animal life. Many scientists, including Charles Darwin made many discoveries that led to the theory of evolution by natural selection while studying the plants and animals on these islands.

inherited traits Features that are passed from one generation to the next.

natural selection Results when some organisms have traits that make them better suited to live in a certain environment than others; they are more likely to survive, reproduce and pass their traits on to future generations than those without the special traits.

species A group of individuals that are genetically related and can breed to produce fertile young.

trait A feature or characteristic of an organism. For example, your height, hair color, and eye shape are physical traits.

Points to Consider

- Evolution by natural selection is supported by extensive scientific evidence. What do you think this evidence consists of?

7.2 Lesson 7.2: Evidence of Evolution

Lesson Objectives

- Understand that the scientific theory of biological evolution is based on extensive physical evidence and testing. This includes:
  - differences between fossils in different layers of rock
  - the age of rocks and fossils

- vestigial structures
- similarities between embryos of different organisms
- the same DNA and RNA materials found in all organisms
- similar genomes found in almost all organisms.

Check Your Understanding

- Where did Charles Darwin collect evidence of evolution and what kinds of evidence did he find?
- What is natural selection?
- What kinds of traits change through evolution?

Introduction

Though the idea of evolution had been proposed prior to Charles Darwin, most people think of Darwin's name when they think of evolution. Unlike others before him who based their ideas on speculation, opinions, myths, or folklore, Darwin's theories were based on a tremendous amount of scientific evidence.

In 1859, Charles Darwin and Alfred Russel Wallace first presented several forms of evidence of evolution. Their evidence included:

- fossils of extinct species from different eras
- similarities between the embryos of different species
- physical traits of different species
- the behavior of different species
- the distributions of different plant and animal species around the world.

Darwin and other 19th century scientists came to the conclusions they did without knowing anything about molecular biology. Today, even more evidence of evolution by natural selection is coming from molecular biology and genetics. Genetics is also helping explain the mechanisms of how evolution occurs.

The Fossil Record

Paleontologists are the scientists who study fossils to learn about life in the past. **Fossils** are the preserved remains or traces of animals, plants, and other organisms from the distant past. Examples of fossils include bones, teeth, impressions, and leaves. Paleontologists compare the features of species from different periods in history. With this information, they try to unravel how species have evolved over millions of years (**Figure** 26.2). This

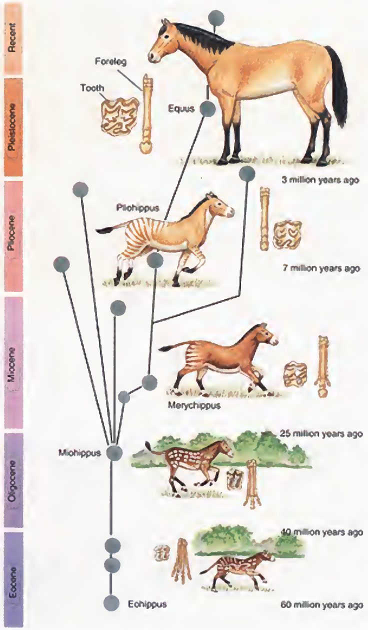

Figure 7.15: Evolution of the horse. Fossil evidence, depicted by the skeletal fragments, demonstrates evolutionary milestones in this process. Notice the 57 million year evolution of the horse leg bones and teeth. Especially obvious is the transformation of the leg bones from having four distinct digits to the hoof formation of today's horse. (3)

method works better with some species than others. For example, it is difficult to track the evolution of bacteria from fossils, because their single cells do not last well as fossils.

Until recently, fossils were the main source of evidence of evolution (**Figures** 7.16 and 7.17). The location of each fossil in layers of rocks provides clues to the age of the species and how species evolved in the past. Older materials and fossils are deeper in the earth; newer fossils and materials are closer to the surface.

Figure 7.16: A fossil is the remains of a plant or animal that existed some time in the distant past. Fossils, such as this one, were found in rocks or soil that was laid down long ago. (17)

Fossils and the rocks they are embedded in provide evidence of how life and environmental conditions have changed throughout Earth's history. They also help us understand how the past and present distribution of life on Earth is affected by earthquakes, volcanoes, and shifting seas, and other movements of the continents.

The Age of Rock Layers and Fossils

The many layers of sedimentary rock provide evidence of the long history of Eearth and the order of life forms whose remains are found in the rocks. The youngest layers are not always found on top, because of folding, breaking, and uplifting of layers. If the layers of earth were tilted by earthquakes or volcanoes, geologists can figure out which layers came from the deepest parts of the Earth.

The fossils and the order in which fossils appear is called the fossil record. This record provides important records of how species have evolved, divided and gone extinct. Methods used to date the age of rocks and fossils make it possible to determine when these events

Figure 7.17: About 40 to 60 million years ago this mosquito and fly were trapped in the gooey stuff, called resin that comes from trees. The fossils in the movie *Jurassic Park*, were trapped in resin. (14)

happened.

Geologist use a method called radiometric dating to determine the age of rocks and fossils in each layer of rock. This technique measures the decay rate of radioactive materials in each rock layer (**Figure** 7.18).

Radiometric dating has been used to determine that the oldest known rocks on Earth are between 4-5 billion years old. The oldest fossils are between 3-4 billion years old.

Vestigial Structures

Millions of species of animals, plants and microorganisms are alive today. Even though two different species may not look similar, they may have similar internal structures, and chemical processes that indicate they can have a common ancestor.

Some of the most interesting kinds of evidence for evolution are body parts that have lost their use through evolution (**Figure** 7.19). Most birds need their wings to fly. But the wings on an ostrich have lost their original use. These are called **vestigial structures**. Penguins do not use their wings to fly in the air; however they do use them to "fly" in the water. A whale's pelvic bones-which were once attached to legs- are also vestigial structures (**Figure** 7.20).

If you look at an x-ray of the bones in your back (called vertebrae), you will see several

Figure 7.18: This device, called a spectrophotometer can be used to measure the level of radioactive decay of certain elements in rocks and fossils to determine their age. (9)

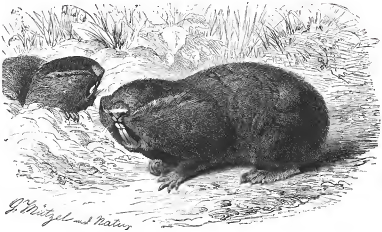

Figure 7.19: Mole rats live under ground where they do not need eyes to find their way around. This mole's eyes are covered by skin. Body parts that do not serve any function are vestigial structures. (22)

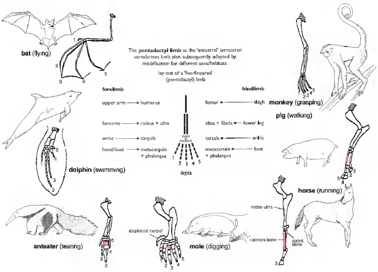

Figure 7.20: The bones in your arms and hands have the same bone pattern as those in the wings, legs, and feet of the animals pictured above. How have the bones adapted for different uses in each animal? (6)

vertebrae that come under your hips. These are called your tailbone. We do not use these small vertebrae; they are further evidence of our evolution.

Embryological Evidence

Some of the oldest evidence of evolution comes from embryology, the study of how organisms develop. An embryo is an animal or plant in its earliest stages of development, before it is born or hatched.

Centuries ago, people recognized that the embryos of many different species have similar appearances (**Figure** 7.21). The embryos of some species are even difficult to tell apart. Many of these animals do not differ much in appearance until they develop further. Many traits of one type of animal appear in the embryo of another type of animal. For example, fish embryos and human embryos both have gill slits. In fish they develop into gills, but in humans they disappear before birth (**Figure** 7.22).

The similarities between embryos suggests that these animals are related and have common ancestors. For example, humans did not evolve from chimpanzees. But the similarities between the embryos of both species may be due to our development from a common ancestor with chimpanzees. As our common ancestor evolved, both humans and chimpanzees developed different traits.

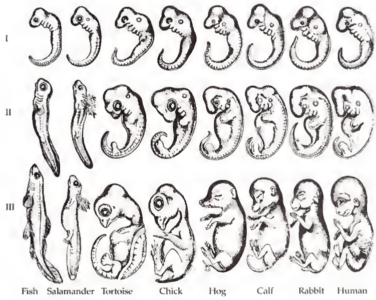

Figure 7.21: This drawing was made to show the similarities between the embryos of many species. Embryos of many different kinds of animals: mammals, birds, reptiles, fish, etc. look very similar. (36)

Figure 7.22: This is a six week old human embryo. Notice the similarities between this embryo and those of the other animals in figure 3. (33)

Similarities Between Molecules and Genomes

Molecular Clocks

Arguably, some of the most significant evidence of evolution comes from examining the molecules and DNA found in all organisms (**Figure** 7.23). The field of molecular biology did not emerge until the 1940s and has since confirmed and extended the conclusions about evolution drawn from other forms of evidence. **Molecular clocks** are used in molecular evolution to relate the time that two species diverged to the number of differences measured between the species' DNA sequences or protein amino acid sequences. These clocks are sometimes called gene clocks or evolutionary clocks. The fewer the differences the less time since the divergence of the species. For example, a chicken and a gorilla will have more differences between their DNA and protein amino acid sequences then a gorilla and an orangutan. This provides additional evidence that the gorilla and orangutan are evolutionally closer related than the gorilla and the chicken.

Molecular clocks, combined with other forms of evidence, such as evidence from the fossil record, has provided considerable evidence to estimate how long ago various groups of organisms diverged evolutionarily from one another.

Molecular Genetics

The development of molecular genetics has revealed the record of evolution left in the genomes of all organisms (**Figure** 7.24). It also provides new information about the relationships among species and how evolution occurs.

Molecular genetics provides evidence of evolution such as:

- the same biochemical building blocks – such as amino acids and nucleotides - are responsible for life in all organisms, from bacteria to plants and animals
- DNA and RNA determines the development of all organisms
- the similarities and differences between the genomes, the gene sequences of each species, reveal patterns of evolution.

Lesson Summary

- Fossil evidence, depicted by the skeletal fragments, demonstrates evolutionary milestones.
- Fossils and the rocks they are embedded in provide evidence of how life and environmental conditions have changed throughout Earth's history.
- The fossils and the order in which fossils appear is called the fossil record.

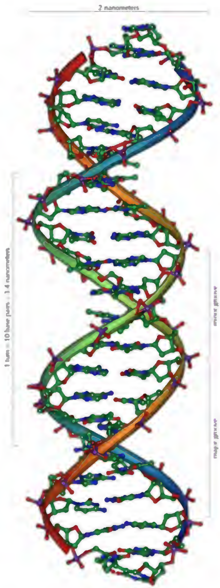

Figure 7.23: Almost all organisms are made from DNA with the same building blocks. The genomes (all of the genes in an organism) of all mammals are almost identical. (24)

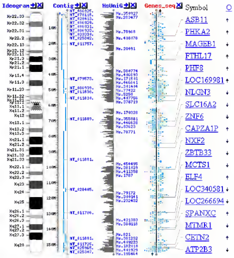

Figure 7.24: This is a map of the genes on just one of the 46 human chromosomes. Similarities and differences between the genomes (the genetic makeup) of different organisms reveal the relationships between the species. The human and chimpanzee genomes are almost identical-just about 1.2% differences between the two genomes. The complexity of the map signifies close evolutionary relationships when the genomes are highly similar. (13)

- Geologist use a method called radiometric dating to determine the age of rocks and fossils in each layer of rock.
- Radiometric dating has been used to determine that the oldest known rocks on Earth are between 4-5 billion years old. The oldest fossils are between 3-4 billion years old.
- Body parts that do not serve any function are called vestigial structures.
- Vestigial structures indicate that two species have a recent common ancestor.
- The similarities between embryos suggests that animals are related and have common ancestors.
- The same biochemical building blocks – such as amino acids and nucleotides - are responsible for life in all organisms, from bacteria to plants and animals.
- DNA and RNA determines the development of all organisms.
- The similarities and differences between the genomes, the gene sequences of each species, reveal patterns of evolution.

Review Questions

1. What are the different kinds of evidence of evolution?
2. How do geologists determine the age of rocks and fossils?
3. What is an embryo?
4. What is a vestigial structure?
5. What is an example of a vestigial structure?

6. What is a genome?
7. What is the most convincing evidence of evolution?
8. How do the embryos of different species support the idea of evolution?

Further Reading / Supplemental Links

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Vocabulary

embryo An animal or plant in its earliest stages of development, before it is born or hatched.

embryology The study of how organisms develop.

fossil The preserved remains or traces of animals, plants, and other organisms from the distant past; examples include bones, teeth, impressions, and leaves.

fossil record Fossils and the order in which fossils appear; provides important records of how species have evolved, divided and gone extinct.

genetics The scientific study of heredity.

genome All of the genes in an organism.

paleontologists Scientists who study fossils to learn about life in the past.

radiometric dating A method to determine the age of rocks and fossils in each layer of rock; measures the decay rate of radioactive materials in each rock layer.

vestigial structure Body part that has lost its use through evolution, such as a whale's pelvic bones.

Points to Consider

- How do you think new species evolve?
- How long do you think it takes for a new species to evolve?

7.3 Lesson 7.3: Macroevolution

Lesson Objectives

- Students will understand the differences between macroevolution and microevolution.
- Students will understand that speciation is the formation of new species.
- Students will understand the mechanisms of speciation.

Check Your Understanding

- Why can't an individual person evolve? Why can only groups evolve over many generations?
- What causes a species or a population to evolve?

Introduction

Small changes or large changes, how does evolution occur? It is easy to think that many small changes, as they accumulate over time, may gradually lead to a new species. Or is it possible that due to severe changes in the environment, large changes are needed to allow species to adapt to the new surroundings? Or are both probable methods of evolution?

Microevolution and Macroevolution

Microevolution

You already know that evolution is the change in species over time, due to the change of how often an inherited trait occurs in a population over many generations. Most evolutionary changes are small and do not lead to the creation of a new species. These small changes are called **microevolution**.

An example of microevolution is the evolution of pesticide resistance in mosquitoes. Imagine that you have a pesticide that kills most of the mosquitoes in your state one year. As a result, the only remaining mosquitoes are the pesticide resistant mosquitoes. When these mosquitoes reproduce the next year, they produce more mosquitoes with the pesticide resistant trait. This is an example of microevolution because the number of mosquitoes with this trait changed. However, this evolutionary change did not create a new species of mosquito, because the pesticide resistant mosquitoes can still reproduce with other mosquitoes if they were put together.

Macroevolution

Macroevolution refers to much bigger evolutionary changes that result in new species. Macroevolution may happen:

1. when many microevolution steps lead to the creation of a new species,
2. as a result of a major environmental change, such as volcanic eruptions, earthquakes or an asteroid hitting Earth, which changes the environment so much that natural selection leads to large changes in the traits of a species.

After thousands of years of isolation from each other, some of Darwin's finch population, which was discussed in the *Evolution by Natural Selection* lesson, will not or cannot breed with other finch populations when they are brought together. Since they do not breed together, they are classified as separate species.

Genotype or Phenotype?

Natural selection acts on the phenotype - the traits or characteristics - of an individual, not on the underlying genotype. For many traits, the homozygous genotype, AA for example, has the same phenotype as the heterozygous Aa genotype. If both an AA and Aa individual have the same phenotype, the environment cannot distinguish between them. So natural selection cannot choose a homozygous individual over a heterozygous individual. If homozygous recessive aa individuals are selected against, that is they are not well adapted to their

environment, acting on the phenotype allows the a allele to be maintained in the population through heterozygous Aa individuals.

Carriers

Because natural selection acts on the phenotype, if an allele is lethal in a homozygous individual, aa for example, it will not be lethal in a heterozygous Aa individual. These heterozygous Aa individuals will then act as carriers of the a allele. This allele is then maintained in the population's gene pool. The gene pool is the complete set of alleles within a population.

Tay-Sachs disease is an autosomal recessive genetic disorder. It is caused by a genetic defect in a single gene with one defective copy of that gene inherited from each parent, rr for example. Affected individuals usually die from complications of the disease in early childhood. Affected individuals must have unaffected parents, each being a carrier of the defective allele, so the parents are heterozygous Rr. This lethal allele is maintained in the gene pool through these unsuspecting heterozygous individuals; they do not show any symptoms of the disease, so most individuals do not get tested to see if they are carriers.

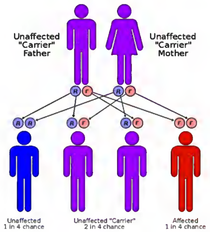

Figure 7.25: Tay-Sachs disease is inherited in the autosomal recessive pattern. Each parent is an unaffected carrier of the lethal allele. (37)

Hardy-Weinberg Equilibrium

The Hardy-Weinberg model (sometimes called a law) states that a population will remain at **genetic equilibrium** - with constant (unchanging) allele and genotype frequencies and

no evolution - as long as five conditions are met:

1. No mutation (no change in the DNA sequence)
2. No migration (no moving into or out of a population)
3. Very large population size
4. Random mating (mating not based on preference)
5. No natural selection.

These five conditions rarely occur in nature. For example, it is highly unlikely that new mutations are not constantly generated. If these five conditions are met, the frequencies of genotypes within a population can be determined given the phenotypic frequencies.

The Hardy-Weinberg Equation

For example, let's use a hypothetical rabbit population of 100 rabbits (200 alleles) to determine allele frequencies for color:

- 9 albino rabbits (represented by the alleles bb) and
- 91 brown rabbits (49 homozygous [BB] and 42 heterozygous [Bb]).

The gene pool contains 140 B alleles [49 + 49 + 42] (70%) and 60 b alleles [9 + 9 + 42] (30%) – which have gene frequencies of 0.7 and 0.3, respectively.

If we assume that alleles sort independently and segregate randomly as sperm and eggs form, and that mating and fertilization are also random, the probability that an offspring will receive a particular allele from the gene pool is identical to the frequency of that allele in the population:

- BB: 0.7 x 0.7 = 0.49
- Bb: 0.7 x 0.3 = 0.21
- bB: 0.3 x 0.7 = 0.21
- bb: 0.3 x 0.3 = 0.09

If we calculate the frequency of genotypes among the offspring, they are identical to the genotype frequencies of the parents. There are 9% bb albino rabbits and 91% BB and Bb brown rabbits. Allele frequency remains constant as well. The population is stable – at a Hardy-Weinberg genetic equilibrium.

A useful equation generalizes the calculations we've just completed. Variables include

- p = the frequency of one allele (we'll use allele B here) and
- q = the frequency of the second allele (b in this example).

We will use only two alleles (so $\mathbf{p} + \mathbf{q}$ must equal 1), but similar equations can be written for more alleles.

Allele frequency equals the chance of any particular gamete receiving that allele. Therefore, when egg and sperm combine, the probability of any genotype is the product of the probabilities of the alleles in that genotype. So:

Probability of genotype ***BB*** = $\boldsymbol{p}$ X $\boldsymbol{p}$ = $\mathbf{p}^2$ and

Probability of genotype ***Bb***= ($\boldsymbol{p}$ X $\boldsymbol{q}$) + ($\boldsymbol{q}$ X $\boldsymbol{p}$) = **2pq** and

Probability of genotype ***bb*** = $\boldsymbol{q}$ X $\boldsymbol{q}$ = $\mathbf{q}^2$

We have included all possible genotypes, so the probabilities must add to 1.0. In our example 0.49 + 2(0.21) + 0.9 = 1. Our equation becomes:

Table 7.1:

$\boldsymbol{p^2}$	+	**2** $\boldsymbol{pq}$	+	$\boldsymbol{q^2}$	=	**1**
frequency of genotype *BB*		frequency of genotype *Bb*		frequency of genotype *bb*		

This is the **Hardy-Weinberg equation**, which describes the relationship between allele frequencies and genotype frequencies for a population at equilibrium.

Genetic Drift

Recall that the third requirement for Hardy-Weinberg equilibrium is a very large population size. This is because variations in allele frequencies that occur by chance are minimal in large populations. In small populations, random variations in allele frequencies can significantly influence the "survival" of any allele. Random changes in allele frequencies in small populations is known as **genetic drift.** As the population (and therefore the gene pool) is small, genetic drift could have substantial effects on the traits and diversity of a population. Many biologists think that genetic drift is a major cause of microevolution.

The Origin of Species

The creation of a new species is called **speciation**. Most new species develop naturally, but humans have also artificially created new subspecies, breeds, and species for thousands of years.

Natural selection causes beneficial heritable traits to become more common in a population, and unfavorable heritable traits become less common. For example, a giraffe's neck is bene-

ficial because it allows the giraffe to reach leaves high in trees. Natural selection caused this beneficial trait to become more common than short necks.

As new mutations (changes in the DNA sequence) are constantly being generated in a population's gene pool, some of these mutations will be beneficial and result in traits that allow adaptation and survival. Natural selection causes evolution through the genetic change of a species as the beneficial traits become more common within a population.

Artificial selection is when humans select which plants or animals to breed to pass specific traits on to the next generation. A farmer may choose to breed only the cows that produce the best milk (the favored traits) and not breed cows that do not produce much milk (a less desirable trait). Humans have also artificially breed dogs to create new breeds (**Figure** 7.26).

Figure 7.26: Artificial Selection: Humans used artificial selection to create these different breeds. Both dog breeds are descended from the same wolves, and their genes are almost identical. Yet there is at least one difference between their genes that determine size. (8)

Reproductive Isolation

There are two main ways that speciation happens naturally. Both processes create new species by isolating groups (populations) of the same species from each other. Organisms can be reproductively isolated from each other either geographically or by some behavior. Over long period of time (usually thousands of years), each population evolves in a different direction. One way scientists test whether two populations are separate species is to bring

them together again. If the two populations do not interbreed and produce fertile offspring, they are separate species.

Geographic Isolation

Allopatric speciation happens when groups from the same species are geographically isolated physically for long periods. Imagine all the ways that plants or animals could be isolated from each other:

- a mountain range
- a canyon water such as rivers, streams, or an ocean
- a desert

Charles Darwin recognized that speciation could happen when some members of a species were isolated from the others for hundreds or thousands of years. Darwin had observed thirteen distinct finch species on the Galápagos Islands that had evolved from the same ancestor. Several of the finch population evolved into separate species while they were isolated on separate islands. Scientists were able to determine which finches had evolved into distinct species by bringing members of each population together. The birds that would not or could not interbreed are regarded as separate species.

A classic example of geographic isolation is the Abert squirrel, shown in **Figures** 7.27) and 7.28). When the Grand Canyon in Arizona formed, squirrels from one species were separated by the giant canyon that they could not cross. After thousands of years of isolation from each other, the squirrel populations on the northern wall of the canyon looked and behaved differently from those on the southern wall. North rim squirrels have white tails and black bellies. Squirrels on the south rim have white bellies and dark tails.

Isolation without Physical Separation

Sympatric speciation happens when groups from the same species stop interbreeding, because of something other than physical separation, such as behavior. The separation may be due to different mating seasons, for example. Sympatric speciation is more difficult to identify.

Some scientists suspect that two groups of orcas (killer whales) live in the same part of the Pacific Ocean part of the year, but do not interbreed. The two groups hunt different prey species, eat different foods, sing different songs, and have different social structures.

Different behaviors may have also led to the emergence of two Galápagos finch species that live in the same space. The two species are separated by behavioral barriers such as mating

Figure 7.27: Abert Squirrel on the southern rim of the Grand Canyon (26)

signals. In this case, members of each group select mates according to different beak structures and bird calls. They do not need physical barriers, because behavioral differences do enough to keep the groups separated.

Allopatric speciation and sympatric speciation are both forms of **reproductive isolation**. Allopatric speciation is due to **geographic isolation**. Sympatric speciation is due to **behavioral isolation**, or isolation due to different mating seasons, which is also known as **temporal isolation**.

Rates of Evolution

How fast is evolution? How long did it take for the giraffe to develop a long neck? How long did it take for the Galápagos finches to evolve? How long did it take for whales to evolve from land mammals? These and other questions about the rate of evolution are difficult to answer, but evidence does exist in the fossil record.

The rate of evolution is a measurement of the speed of evolution. Genetically speaking, evolution is how much an organism's genotype (the genes that make up an individual) changes over a set period of time. Evolution is usually so gradual that we do not see the change for many, many generations. Humans took millions of years to evolve from a mammal that is now extinct.

Not all organisms evolve at the same rate. It would be difficult to measure evolution on your family because you are only looking at a small population over a few generations. However

Figure 7.28: Kaibab squirrel (a subspecies of Abert's) found on northern rim of the Grand Canyon (19)

there are organisms that are evolving so fast that you may be able to observe evolution! Many scientists use bacteria or other species that reproduce frequently to study evolution. Species with short life cycles and that reproduce frequently evolve much faster than others. Bacteria evolve hundreds (or thousands or more) of times faster than humans do. Bacteria go through so many generations in a few days, that we can actually witness evolution. A human takes about 22 years to go through one generation. But some bacteria go through over a thousand generations in less than two months.

Evolutionary Trees

Charles Darwin came up with the idea of an evolutionary tree to represent the relationships between different species and their common ancestors (**Figure** 7.29). The base of the tree represents the ancient ancestors of all life. The separation into large branches shows where these original species evolved into increasingly different populations that would not come back together again. The branches keep splitting into smaller and smaller branches as species continue to evolve into more and more species. Some species are represented by short twigs spurting out of the tree, then stopping. These are species that went extinct before evolving into new species. Other "Trees of Life" have been created by other scientists (**Figure** 7.30).

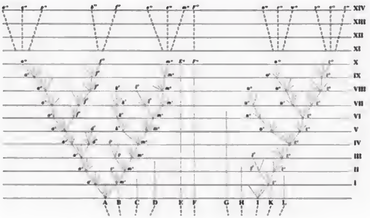

Figure 7.29: Darwin drew this version of the "Tree of Life" to represent how species evolve and diverge into separate directions. Each point on the tree where one branch splits off from another represents the common ancestor of the species on the separate branches. (25)

Theory?

Darwin's Theory of Evolution by Natural Selection is supported by well over 150 years of scientific evidence, ranging from fossil evidence to DNA evidence. By definition, this is a well tested scientific theory. An abundance of scientific evidence supports this theory. The

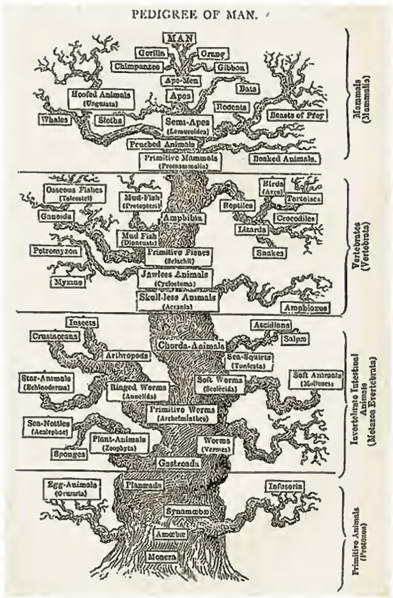

Figure 7.30: Scientists have drawn many different versions of the "Tree of Life" to show different features of evolution. This "Tree of Life" was made by Ernst Haeckel in 1879. (5)

world is very old and has undergone some dramatic changes. Life has been on the planet for most of that time. As you will see in the next lesson, life started as single celled organisms and has evolved over billions of years into complex plants and animals. But this journey has not been easy. Most species that have ever lived are now extinct. There have been a number of mass extinctions, where many species vanished all at once. It is because of the tremendous diversity of species that has allowed some to adapt to whatever changes nature throws in its path, from small changes to major environmental disturbances. So it is nature that selects - hence *Natural Selection* - which species adapts, survives and evolves.

Lesson Summary

- Microevolution results from evolutionary changes that are small and do not lead to the creation of a new species.
- Macroevolution refers to large evolutionary changes that result in new species.
- Macroevolution may happen when many microevolution steps lead to the creation of a new species.
- Macroevolution may happen as a result of a major environmental change, such as volcanic eruptions, earthquakes or an asteroid hitting Earth, which changes the environment so much that natural selection leads to large changes in the traits of a species
- The creation of a new species is called speciation.
- Natural selection causes beneficial heritable traits to become more common in a population, and unfavorable heritable traits become less common.
- Artificial selection is when humans select which plants or animals to breed to pass specific traits on to the next generation.
- Allopatric speciation occurs when groups from the same species are geographically isolated physically for long periods.
- Sympatric speciation occurs when groups from the same species stop interbreeding, because of something other than physical separation, such as behavior.
- Allopatric speciation and sympatric speciation are both forms of reproductive isolation.
- The rate of evolution is a measurement of the speed of evolution. Genetically speaking, evolution is how much an organism's genotype changes over a set period of time.
- Not all organisms evolve at the same rate.
- Evolutionary trees are used to represent the relationships between different species and their common ancestors.

Review Questions

1. What is the difference between macroevolution and microevolution?
2. What conditions cause organisms to evolve and adapt?
3. What do the branches on the Tree of Life represent?
4. Which organism has a faster rate of evolution: a human or a bacterium?

5. How do you know if two related organisms are members of the same species?
6. Why do the squirrels on opposite side of the Grand Canyon look different?
7. How is artificial selection different from natural selection?
8. What, other than physical isolation, could cause a species to split into two different directions of evolution?

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Vocabulary

allopatric speciation Speciation that occurs when groups from the same species are geographically isolated physically for long periods.

artificial selection Occurs when humans select which plants or animals to breed to pass specific traits on to the next generation.

behavioral isolation The separation of a population from the rest of its species due to some behavioral barrier, such as having different mating seasons.

evolutionary tree Diagram used to represent the relationships between different species and their common ancestors.

genotype The genes that make up an individual.

geographic isolation The separation of a population from the rest of its species due to some physical barrier, such as a mountain range, an ocean, or great distance.

macroevolution Big evolutionary changes that result in new species.

microevolution Small changes in inherited traits; does not lead to the creation of a new species.

natural selection Causes beneficial heritable traits to become more common in a population, and unfavorable heritable traits become less common.

primate A group of related mammal species that have binocular vision, specialized hands and feet for grasping, and enlarged and differentiated brains; includes humans, chimpanzees, the apes, monkeys, and lemurs.

reproductive isolation allopatric and sympatric speciation; isolation due to geography or behavior, resulting in the inability to reproduce.

speciation The creation of a new species; either by natural or artificial selection.

sympatric speciation Speciation that occurs when groups from the same species stop interbreeding, because of something other than physical separation, such as behavior.

temporal isolation Isolation due to different mating seasons.

Points to Consider

- How long do you think humans have been around?
- How long do you think Earth existed before life formed?
- For how much of Earth's history have humans existed?

7.4 Lesson 7.4: History of Life on Earth

Lesson Objectives

- Know that geologists and paleontologists use evidence to determine the history of Earth and life on Earth.
- Know that geologists and paleontologists measure the radioactivity in certain rocks to determine the age of the earth and fossils.
- Know that the earth is between four and five billion years old.
- Know that scientists need to know what the environment (what chemicals were around, the temperature, etc.) was like on Earth billions of years ago to know how life formed.

Check Your Understanding

- What are fossils?
- How does the fossil record contribute to the evidence of evolution?

Introduction

It is no surprise that people have wondered about the age of the earth, how it was formed, and how life began on Earth for hundreds, even thousands, of years. Try to imagine how ancient philosophers tried to explain the history of the earth and life. Many people used mythology or cultural beliefs to explain elaborate stories about how and when the earth formed.

The past two to three hundred years has been an exciting time for geologists, paleontologists and other scientists who are trying to trace the history of the earth. What was once a hobby, studying land forms and fossils has become a science that is revealing the history of the earth and life on Earth.

Age of Earth

During the 1800s, geologists, paleontologists and naturalists found several forms of physical evidence that confirmed that the earth is very old, far older than the 6,000 years that some leaders had claimed. Their evidence included:

- Fossils of ancient sea life on dry land far from oceans: This supported the idea that the earth changed over time and that some dry land today was once covered by oceans.
- The many layers of rock: When people realized that rock layers represent the order in which rocks and fossils appeared, they were able to start to trace the history of the earth and life on Earth.
- Indications that volcanic eruptions, earthquakes and erosion that happened long ago shaped much of the earth's surface. This supported the idea of an older Earth.

Radiometric Dating

During the past one hundred years, geologists and paleontologists have been able to delve even deeper into the earth's history with new tools of science. The most convincing method, called **radiometric dating**, was developed more than one hundred years ago. Rocks are made up of minerals. Scientists found that they could measure the age of rocks by measuring the radioactivity of certain minerals in rocks. Geologists and paleontologists still use variations of radiometric dating to determine the age of fossils and rocks today (**Figure** 7.31).

Figure 7.31: The most reliable way to figure out the earth's age is to measure the radioactivity of certain minerals found in rocks (called radiometric dating). This mass spectrophotometer can also be used to measure age of fossils from the level of radiation in minerals surrounding the fossil. (1)

Over 4 Billion Years

The earth is at least as old as its oldest rocks. The oldest rock minerals found on Earth so far are zircon crystals that are at least 4.404 billion years old. These tiny crystals were found in the Jack Hills of Western Australia. Since the earth is at least as old as the oldest minerals found on Earth, geologists estimate that the minimum age of the earth is 4.404 billion years.

Likewise, the earth cannot be any older than the solar system. The oldest possible age of the earth is 4.57 billion years old, the age of the solar system. Geologists and geophysicists based the age of the universe on the age of materials within meteorites that are formed within the solar system.

Origin of Life on Earth

There is good evidence that life has probably existed on Earth for most of Earth's history. Some of the oldest fossils of life forms on Earth are at least 3.5 billion year old fossils of blue green algae found in Australia (**Figure** 7.32).

The next step is to determine exactly how life formed billions of years ago. First, scientists need to know what the environment was like 3.5 to 4 billion years ago; they need to know

Figure 7.32: Some of the oldest fossils on earth are stromolites, made of algae and a kind of bacteria, found along the coast of Australia. (11)

what kinds of materials were available then that could have been involved in the creation of life. Scientists believe the early earth contained no oxygen gas, but did contain other gases, including nitrogen, carbon dioxide, carbon monoxide, water vapor, hydrogen sulfide and probably a few others.

Life from Random Reactions

Today, we have evidence that life on Earth came from random reactions between chemical compounds that formed molecules; in a series of random steps, these molecules created proteins and nucleic acids (RNA or DNA), and then cells. We know that the ingredients for life (the building blocks of life), were present at the beginning of Earth's history. Some chemicals were in water and volcanic gases. Other chemicals would have come from meteorites in space. Energy to drive chemical reactions was provided by volcanic eruptions and lightening. Keep in mind that this process may have taken as much as 1 billion years. Our understanding of how life originated on Earth is developing gradually (**Figure** 7.33).

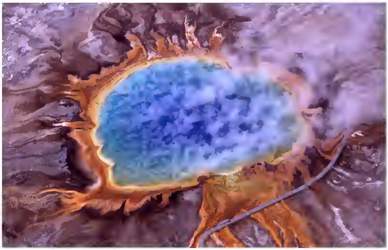

Figure 7.33: Some clues to the origins of life on Earth come from studying the early life forms that developed in hot springs, such as the Grand Prismatic Spring at Yellowstone National Park. This spring is approximately 250 feet by 300 feet wide. (38)

Geologic Time Scale

Geologists and other earth scientists use geologic time scales to describe when events occurred throughout the history of Earth. The time scales can be used to illustrate when both geologic events and events affecting plant and animal life occurred. All of the earth events we see happening today, such as earthquakes, volcanic eruptions, and erosion, have happened

throughout history. Past catastrophic events, such as asteroids and comets also hit the earth long before humans evolved.

The geologic time scale in **Figure** 7.34 illustrates the timing of events such as:

- earthquakes
- volcanic eruptions
- major erosion
- meteorites hitting Earth
- the first signs of life forms
- mass exterminations

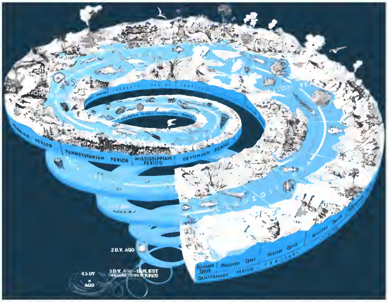

Figure 7.34: The geological time scale of Earth's past is organized according to events which took place during different periods on the time scale. Geologic time is the same as the age of the earth: between 4.04 and 4.57 billion years. Look closely for such events as the extinction of dinosaurs and many marine animals. (10)

Evolution of Major Life Forms

Life on Earth began about 3.5 to 4 billion years ago. The first life forms were single cell organisms, prokaryotic organisms, similar to bacteria. The first multicellular organisms did not appear until about 610 million years ago in the oceans. These of course would be eukaryotic organisms. Some of the first multicellular forms included sponges, brown algae, and slime molds.

Many of the modern types of organisms we know today evolved during the next ten million years in an event called the Cambrian explosion. This sudden burst of evolution may have been triggered by some environmental changes that made the environment more suitable for a wider variety of life forms.

Plants and fungi did not appear until roughly 500 million years ago. They were soon followed by arthropods (insects and spiders). Next came the amphibians about 300 million years ago, followed by mammals around 200 million years ago and birds around 100 million years ago.

Even though large life forms have been very successful on Earth, most of the life forms on Earth today are still prokaryotes – small, single celled organisms. Fossils indicate that many organisms that lived long ago are extinct. Extinction of species is common; in fact, it is estimated that 99% of the species that have lived on the earth no longer exist.

The basic timeline of Earth is a 4.6 billion year old Earth, with (very approximately):

- about 3.5 - 3.8 billion years of simple cells (prokaryotes)
- 3 billion years of photosynthesis
- 2 billion years of complex cells (eukaryotes)
- 1 billion years of multicellular life
- 600 million years of simple animals
- 570 million years of arthropods (ancestors of insects, arachnids and crustaceans)
- 550 million years of complex animals
- 500 million years of fish and proto-amphibians
- 475 million years of land plants
- 400 million years of insects and seeds
- 360 million years of amphibians
- 300 million years of reptiles
- 200 million years of mammals
- 150 million years of birds
- 130 million years of flowers
- 65 million years since the non-avian dinosaurs died out
- 2.5 million years since the appearance of *Homo*
- 200,000 years since humans started looking like they do today
- 25,000 years since *Neanderthals* died out

Mass Extinctions

Extinctions are part of natural selection. Species often go extinct when their environment changes and they do not have the traits they need to survive. Only those individuals with the traits needed to live in a changed environment survive (**Figure** 7.35).

Mass extinctions, such as the extinction of dinosaurs and many marine mammals, happened after major catastrophes such as volcanic eruptions and major earthquakes changed the

Figure 7.35: Humans have caused many extinctions by introducing species to new places. For example, many of New Zealand's birds have adapted to nesting on the ground. This was possible because there were no land mammals in New Zealand until Europeans arrived and brought cats, fox and other predators with them. Several of New Zealand's ground nesting birds, such as this flightless kiwi, are now extinct or threatened because of these predators. (28)

environment. Scientists have been looking for evidence of why dinosaurs went extinct over fairly short periods. Many scientists are examining the theory that a major cataclysmic events, such as an asteroid colliding with Earth, may have caused the extinction of dinosaurs 65 million years ago (**Figure** 7.36).

Figure 7.36: The fossil of Tarbosaurus, one of the land dinosaurs that went extinct during one of the mass extinctions. (21)

Since life began on Earth, there have been several major mass extinctions. If you look closely at the geological time scale, you will find that at least five major massive extinctions have occurred in the past 540 million years. In each mass extinction, over 50% of animal species died. The total number of extinctions could be as high as 20 mass extinctions during this period.

The fossil record tells the story of these mass extinctions: millions of species of fish, amphibians, reptiles, birds, mammals, mosses, ferns, conifers, flowering plants, and fungi populated the seas and covered the Earth - as continents crashed together and broke apart, glaciers advanced and retreated, and meteors struck, causing massive extinctions. Two specific extinctions occurred at the end of the Permian period and when the dinosaurs went extinct.

At the end of the Permian, an estimated 99.5% of individual organisms perished. Several factors may have contributed, and one factor relates again to the supercontinent Pangaea. Marine biodiversity is greatest in shallow coastal areas. A single continent has a much smaller shoreline than multiple continents of the same size. Perhaps this smaller shoreline contributed to the dramatic loss of species, for up to 95% of marine species perished, compared to “only” 70% of land species. Although the exact cause remains unknown, fossils clearly document the fact of Earth’s most devastating extinction.

Figure 7.37: The supercontinent Pangaea encompassed all of today's continents in a single land mass. This configuration limited shallow coastal areas which harbor marine species, and may have contributed to the dramatic event which ended the Permian - the most massive extinction ever recorded. (16)

The dramatic extinction of all dinosaurs (except those which led to birds) marked the end of the Cretaceous period. A worldwide iridium-rich layer, dated at 65.5 million years ago, provides evidence for a dramatic cause for their ultimate extinction. Iridium is rare in the Earth's crust, but common in comets and asteroids. Scientists associate this layer with a huge crater in the Yucatan and Gulf of Mexico. A collision/explosion between the Earth and a comet or asteroid could have spread debris which set off tsunamis, altered the climate (including acid rain), and reduced sunlight 10-20%. A consequent reduction in photosynthesis would have caused a drastic decrease in food chains, leading to the extinction of the dinosaurs. The fossil record obviously depicts the presence of dinosaurs on Earth, and the absence of dinosaur fossils after this extinction event demonstrates the relationship between the fossil record and evolution.

Figure 7.38: The fossil record demonstrates the presence of dinosaurs, which went extinct over 65 million years ago. (39)

After each mass extinction, open ecological niches are quickly filled by other species. This is well documented in the fossil record. This episodic speciation following an event such as a mass extinction also shows the relationship between evolution and the fossil record.

Lesson Summary

- During the 1800s, geologists, paleontologists and naturalists found several forms of physical evidence that confirmed that the earth is very old.

Figure 7.39: Mammals and birds quickly invaded ecological niches formerly occupied by the dinosaurs. Mammals included monotremes (A), marsupials, and hoofed placentals (B). Modern sharks (C) patrolled the seas. Birds included the giant flightless *Gastornis* (D). (34)

- Fossils of ancient sea life on dry land far from oceans supported the idea that the earth changed over time and that some dry land today was once covered by oceans.
- The many layers of rock represent the order in which rocks and fossils appeared.
- Indications that volcanic eruptions, earthquakes and erosion that happened long ago shaped much of the earth's surface.
- Radiometric dating allows scientists to measure the age of rocks by measuring the radioactivity of certain minerals in rocks.
- The oldest rock minerals found on Earth so far are zircon crystals that are at least 4.404 billion years old.
- Some of the oldest fossils of life forms on Earth are at least 3.5 billion year old fossils of blue green algae found in Australia.
- Scientists believe the early earth contained no oxygen gas, but did contain other gases, including nitrogen, carbon dioxide, carbon monoxide, water vapor, hydrogen sulfide and probably a few others.
- Geologists and other earth scientists use geologic time scales to describe when events occurred throughout the history of Earth.
- The geological time scale of Earth's past is organized according to events which took place during different periods on the time scale.
- Life on Earth began about 3.5 to 4 billion years ago.
- The first life forms were single cell organisms, prokaryotic organisms, similar to bacteria.
- The first multicellular organisms did not appear until about 610 million years ago in

the oceans. Some of the first multicellular forms included sponges, brown algae, and slime molds.

- Plants and fungi appeared roughly 500 million years ago. They were soon followed by arthropods (insects and spiders).
- Amphibians evolved about 300 million years ago, followed by mammals around 200 million years ago and birds around 100 million years ago.
- Extinction of species is common; in fact, it is estimated that 99% of the species that have lived on the earth no longer exist.
- Mass extinctions, such as the extinction of dinosaurs and many marine mammals, happened after major catastrophes such as volcanic eruptions and major earthquakes changed the environment.
- There have been at least five major massive extinctions have occurred in the past 540 million years.
- In each mass extinction, over 50% of animal species died.

Review Questions

1. How do scientists determine the age of a rock or fossil today?
2. How do we know the maximum possible age of the Earth?
3. How do we know the minimum possible age of the Earth?
4. How old is the Earth, based on current evidence?
5. Why is it difficult to determine how life started on Earth?
6. How long ago did life start on Earth?
7. When did mammals first appear on Earth?
8. What kinds of events are recorded on a geological time scale?

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Vocabulary

Cambrian explosion A sudden burst of evolution that may have been triggered by some environmental changes that made the environment more suitable for a wider variety of life forms.

extinct Something that does not exist anymore; a group of organisms that has died out without leaving any living representatives.

mass extinction An extinction when many species go extinct during a relatively short period of time.

radiometric dating A method to determine the age of rocks and fossils in each layer of rock; measures the decay rate of radioactive materials in each rock layer.

stromolites Fossils made of algae and a kind of bacteria; some of the oldest fossils on Earth.

Points to Consider

The next chapter focuses on prokaryotic organisms. Remember, prokaryotes lived on this planet for two billion years before eukaryotic cells even existed.

- Discuss with your class what you think are some of the characteristics, and some of the differences, of prokaryotic organisms.

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Chapter 8

Prokaryotes

8.1 Lesson 8.1: Bacteria

Lesson Objectives

- Describe the cellular features of bacteria.
- Explain the ways in which bacteria can obtain energy.
- Explain how bacteria reproduce themselves.
- Identify some ways in which bacteria can be helpful.
- Identify some ways in which bacteria can be harmful.

Check Your Understanding

- How do prokaryotic and eukaryotic cells differ?

Answer: Eukaryotic cells have a membrane-bound nucleus while prokaryotes do not.

- What are some components of all cells, including bacteria?

Answer: cell membrane, cytoplasm, etc.

Introduction

About 3.5 billion years ago, long before the first plants, people, or other animals appeared, prokaryotes were the first life forms on Earth. Recall that **prokaryotes** are single-celled organisms that lack a nucleus, and that the prokaryotes include bacteria and archaea. For

at least a billion years, Bacteria and Archaea ruled the Earth as the only existing organisms. Even though life is much more diverse on Earth today, bacteria (singular: bacterium) are still the most abundant organisms on Earth. You probably know bacteria as "germs" that cause disease, but as you will see, they can also do many helpful things for the environment and humankind.

Characteristics of Bacteria

Bacteria are so small that they can only be visualized with a microscope. When viewed under the microscope, they have three distinct shapes. These three shapes allow bacteria to be classified by their shape. The **bacilli** are rod-shaped, the **cocci** are sphere-shaped, and the **spirilli** are spiral-shaped (**Figures** 8.1, 8.2 and 8.3).

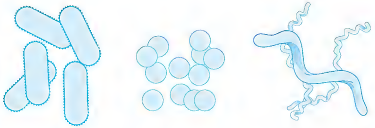

Figure 8.1: Bacteria come in many different shapes. Some of the most common shapes are bacilli (rods), cocci (spheres), and spirilli (spirals). Bacteria can be identified and classified by their shape. (7)

Bacteria are surrounded by a cell wall consisting of **peptidoglycan**, a complex molecule consisting of sugars and amino acids. The cell wall is important for protecting the bacteria. In fact the cell wall is so important that some antibiotics, such as penicillin, work to kill bacteria by preventing the proper synthesis of the cell wall. In parasitic bacteria, which depend on a host organism for energy and nutrients, capsules or slime layers surround the cell wall help defend against the host's defenses.

Recall that all prokaryotes, including the bacteria, lack the membrane-bound organelles and nucleus of eukaryotic cells (**Figure** 8.4). Like eukaryotic cells, however, prokaryotic cells do have cytoplasm, the fluid inside the cell; a plasma membrane, which acts as another barrier; and ribosomes, where proteins are assembled. The DNA of bacteria is mostly contained in a large circular strand, forming a single chromosome, that is compacted into a structure called the **nucleoid.** Many bacteria also have additional small rings of DNA known as **plasmids.**

Some bacteria also have tail-like structures called *flagella* (**Figure** 8.5). The flagella assist the bacteria with movement. As the flagella rotate, they spin the bacteria and propel them

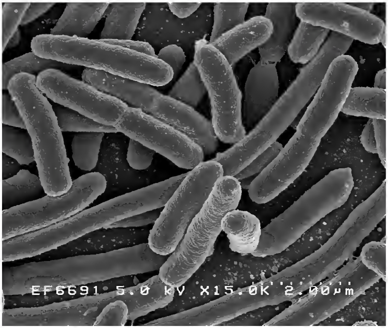

Figure 8.2: *Escherichia coli* is an example of bacteria that are rod-shaped, or bacilli. (2)

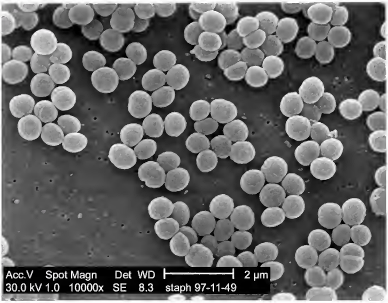

Figure 8.3: *Staphylococcus aureus* is an example of bacteria that are sphere-shaped, or cocci. (3)

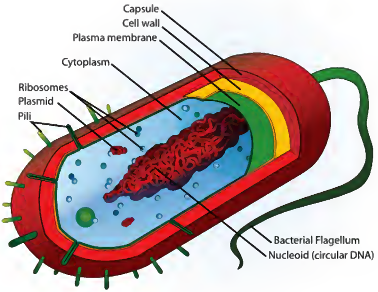

Figure 8.4: The structure of a bacterial cell is distinctive from the eukaryotic cell because of features such as an outer cell wall and the circular DNA of the nucleoid, and the lack of membrane-bound organelles. (5)

forward.

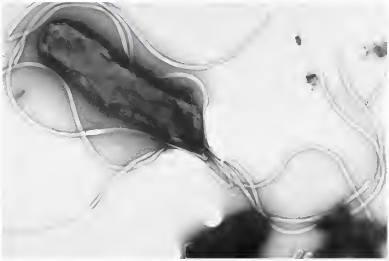

Figure 8.5: The flagella facilitate movement in bacteria. Bacteria may have one, two, or many flagella - or none at all. (6)

Obtaining Food and Energy

Bacteria obtain energy and nutrients from a variety of different methods. Bacteria known as decomposers break down wastes and dead organisms into smaller molecules to obtain nutrients and energy.

Photosynthetic bacteria use the energy of the sun, together with carbon dioxide, to make their own food (discussed in the *Cell Functions* chapter). Briefly, in the presence of sunlight, carbon dioxide and water is converted into glucose and oxygen. The glucose is then converted into usable energy. Glucose is, in essence, the "food" of the bacteria. An example of photosynthetic bacteria is **cyanobacteria,** as seen in **Figure** 8.6.

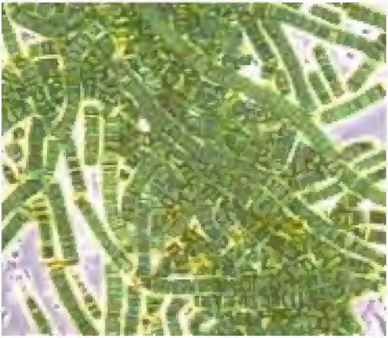

Figure 8.6: Cyanobacteria are photosynthetic bacteria. These bacteria carry out all the reactions of photosynthesis within the cell membrane and in the cytoplasm; they do not need chloroplasts. (10)

Bacteria can also be chemotrophs. **Chemotrophs** obtain energy by breaking down chemical compounds in their environment, such as nitrogen-containing ammonia. They do not use the energy from the sun. This process is important, for example, for the cycling of nitrogen through the environment. As nitrogen can not be made by living organisms, it must be continually recycled. Organisms need nitrogen to make organic compounds, such as DNA.

Some bacteria depend on other organisms for survival. For example, mutualistic bacteria live in the root nodules of legumes, such as pea plants, and make nitrogen available to the plants; in this relationship both the bacteria and the plant benefit. Other bacteria are parasitic and

can cause illness. In a bacterial parasitic relationship, the bacteria benefit and the other organism is harmed. Harmful bacteria will be discussed later in the lesson.

Reproduction in Bacteria

Bacteria reproduce asexually through **binary fission.** During binary fission the chromosome copies itself (replicates), forming two genetically identical copies, then the cell enlarges and divides into two new daughter cells. The two daughter cells are identical to the parent cell (**Figure** 8.7).

Binary fission can happen very rapidly. Some species of bacteria have been shown to double their populations in less than ten minutes! (**Figure** 8.8)

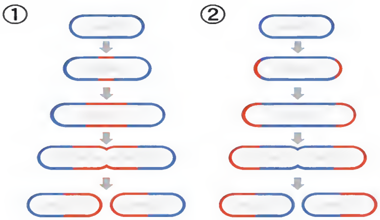

Figure 8.7: Bacteria cells reproduce by binary fission, resulting in two daughter cells identical to the parent cell. (11)

Sexual reproduction does not occur in bacteria, but genetic recombination, the combining and exchange of DNA, does happen in bacteria through three different methods: conjugation, transformation, and transduction. In **conjugation,** DNA passes through the sex pilus, a hairlike extension on the surface of many bacteria, that temporarily joins two bacteria. In **transformation,** bacteria pick up pieces of DNA from their environment. In **transduction,** bacteriophages, viruses that infect bacteria, carry DNA from one bacteria to another.

Helpful Bacteria

Bacteria are crucial in nature since they are common **decomposers,** organisms that break down dead materials and waste products. This decomposition of dead organisms is necessary so that the nutrients in their bodies can be recycled back into the environment. This recycling of nutrients, such as nitrogen, is essential for living organisms; organisms cannot produce

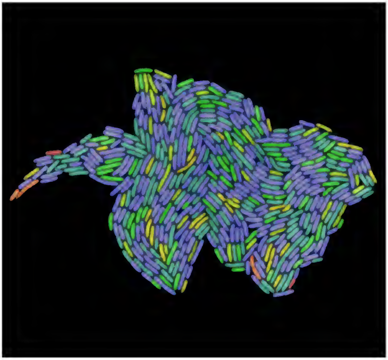

Figure 8.8: Bacteria can divide rapidly. This image is of a growing colony of *E. coli* bacteria. In the right environment the growth and division of two *E. coli* can form a colony of hundreds of bacteria in just a few hours. (12)

nutrients, so they must come from other sources. We get them from the food we eat; plants get them from the soil. How do these nutrients get into the soil? One way is from the actions of decomposers. So without decomposers, we would eventually run out of materials essential for our survival. We also depend on bacteria to decompose our wastes in sewage treatment plants.

Bacteria also help you digest your food. Several species of bacteria, such as *E. coli*, are found in large amounts in your digestive tract. In fact, bacteria cells outnumber your own cells in your gut!

Bacteria are involved in producing some foods. Yogurt is made by using bacteria to ferment milk, and cheese can also be made from milk with the help of bacteria (**Figure** 8.9). Furthermore, fermenting cabbage with bacteria produces sauerkraut.

Figure 8.9: Yogurt is made from milk fermented with bacteria. The bacteria ingest natural milk sugars and release lactic acid as a waste product, which causes proteins in the milk to form into a solid mass, which becomes the yogurt. (1)

In the laboratory, bacteria can be altered to provide us with a variety of useful materials. Bacteria can be used as tiny factories to produce desired chemicals and medicines. For example, insulin, which is necessary to treat people with diabetes, can be produced from bacteria. Through the process of transformation, the human gene for insulin is placed into bacteria. The bacteria then turn that gene into a protein. The protein can be isolated and used to treat patients. The mass production of insulin by bacteria made this medicine more affordable for patients.

Harmful Bacteria

There are also ways that bacteria can be harmful to humans and other animals. Various species of bacteria are responsible for many types of human illness, including strep throat, tuberculosis, pneumonia, leprosy, and Lyme disease. The Black Death (also known as Plague), which killed at least one third of Europe's population in the 1300's, is believed to have been caused by the bacterium *Yersinia pestis.*

Bacterial contamination can also lead to outbreaks of food poisoning. Raw eggs and undercooked meats can contain bacteria that can cause digestive tract problems. Foodborne infection can be prevented by cooking meat thoroughly and washing surfaces that have been in contact with raw meat. Washing of hands before and after handling food is also important.

Some bacteria also have the potential to be used as biological weapons by terrorists. An example is anthrax, a disease caused by the bacterium *Bacillus anthracis.* Since inhaling the spores of this bacterium can lead to a fatal infection, it is a dangerous weapon. In 2001, an act of terrorism in the United States involved *B. anthracis* spores sent in letters through the mail.

Lesson Summary

- Bacteria contain a cell wall containing peptidoglycan and a single chromosome contained in the nucleoid.
- Bacteria can obtain energy through several means including photosynthesis, decomposition, and parasitism, symbiosis, and chemosynthesis.
- Bacteria reproduce through binary fission.
- Bacteria are important decomposers in the environment and aid in digestion.
- Some bacteria can be harmful when they contribute to disease, food poisoning, or biological warfare.

Review Questions

1. What are prokaryotes?
2. What are the possible shapes that bacteria can have?
3. What is the purpose of the flagella?
4. Describe the DNA of bacteria.
5. How do bacteria reproduce?
6. How do bacteria assure genetic recombination?
7. What is a chemoautotroph?
8. How do cyanobacteria obtain energy?
9. How are bacteria important in nature?
10. How can you avoid becoming sick from the bacteria that cause food poisoning?

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- http://www.cdc.gov/ncidod/dvbid/plague/index.htm
- http://www.cdc.gov/nczved/dfbmd/disease_listing/salmonellosis_gi.html
- http://www.ucmp.berkeley.edu/bacteria/bacteria.html
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- http://www.cellsalive.com/cells/bactcell.htm
- http://www.microbeworld.org/microbes/bacteria
- http://en.wikipedia.org/wiki

Vocabulary

bacilli Rod-shaped bacteria or archaea.

binary fission Type of asexual reproduction where a parent cell divides into two identical daughter cells.

cocci Sphere-shaped bacteria or archaea.

chemotrophs Organisms that obtain energy by oxidizing compounds in their environment.

conjugation The transfer of genetic material between two bacteria.

cyanobacteria Photosynthetic bacteria.

decomposers Organisms that break down wastes and dead organisms and recycle their nutrients back into the environment.

flagella Long, tail-like appendages that allow movement.

nucleoid The prokaryotic DNA consisting of a condensed single chromosome.

peptidoglycan Complex molecule consisting of sugars and amino acids that makes up the bacterial cell wall.

plasmid Ring of accessory DNA in bacteria.

prokaryotes Organisms that lack a nucleus and membrane-bound organelles; bacteria and archaea.

transduction Transfer of DNA between two bacteria with the aid of a bacteriaphage.

transformation Changing phenotypes due to the incorporation ("taking up") of foreign DNA from the environment.

spirilli Spiral-shaped bacteria or archaea.

Points to Consider

- In the next section we will discuss the Archae. "Archae" shares the same root word as "archives" and "archaic," so what do you think it means?
- What do you think the earliest life forms on Earth looked like?
- How do you think these early life forms obtained energy?

8.2 Lesson 8.2: Archaea

Lesson Objectives

- Identify the differences between archaea and bacteria.
- Explain how the archaea can obtain energy.
- Explain how the archaea reproduce.
- Discuss the unique habitats of the archaea.

Check Your Understanding

- What are the three shapes of bacteria?

Answer: The bacilli are rod-shaped, the cocci are sphere-shaped, and the spirilli are spiral-shaped.

- How do bacteria reproduce?

Answer: Through binary fission, producing genetically identical organisms.

- How can bacteria be harmful?

Answer: Bacteria can cause diseases such as strep throat. They can also be involved with food poisoning and biological warfare.

Introduction

For many years, archaea were classified as bacteria. However, when modern techniques allowed scientists to compare the DNA of the two prokaryotes, they found that there were two distinct types of prokaryotes, which they named archaea and bacteria. Even though the two groups might seem similar, archaea have many features that distinguish them from bacteria.

1. The cell walls of archaea are distinct from those of bacteria. In most archaea the cell wall is assembled from surface-layer proteins, providing both chemical and physical protection. The cell wall acts as a barrier, preventing macromolecules from coming into contact with the cell membrane. In contrast to bacteria, most archaea lack peptidoglycan in their cell walls.
2. The plasma membranes of the archaea also are made up of lipids that are distinct from those in other organisms.
3. Furthermore, the ribosomal proteins of the archaea resemble those of eukaryotic cells; the ribosomal proteins of archaea are different from those found in bacteria.

Although archaea and bacteria share some fundamental differences, they are still similar in many ways.

1. They both are unicellular, microscopic organisms that can come in a variety of shapes (**Figure** 8.10).
2. Both archaea and bacteria have a single circular chromosome of DNA and lack membrane-bound organelles.
3. Like bacteria, the archaea can have flagella to assist with movement.

Obtaining Food and Energy

Most archaea are chemotrophs and derive their energy and nutrients from breaking down molecules from their environment. A few species of archaea are photosynthetic and capture the energy of sunlight; chemotrophs do not capture the energy from sunlight. Unlike bacteria, which can be parasites and are known to cause a variety of diseases, there are no known archaea that act as parasites. Some archaea do live within other organisms, however, but form mutualistic relationships with their host, where both the archaea and host benefit. In other words, they actually assist the host in some way, for example by helping to digest food.

Reproduction

Like bacteria, reproduction in archaea is asexual. Archaea can reproduce through binary fission, where a parent cell divides into two genetically identical daughter cells. Archaea can

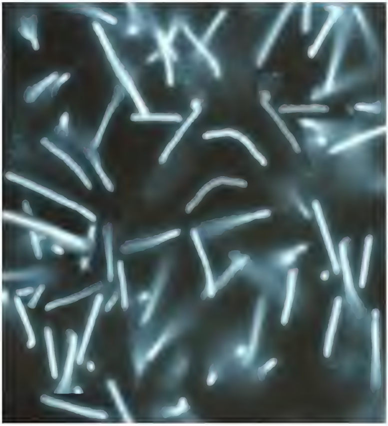

Figure 8.10: Archaea shapes can vary widely, but some are bacilli, or rod-shaped. (4)

also reproduce asexually through budding and fragmentation, where pieces of the cell break off and form a new cell, also producing genetically identical organisms.

Types of Archaea

The first archaea described were unique in that they could survive in extremely harsh environments where no other organisms could survive. For example, the **halophiles**, which means "salt-loving," live in environments with high levels of salt (**Figure** 8.11). They have been identified in the Great Salt Lake in Utah and in the Dead Sea between Israel and Jordan, which have salt concentrations several times that of the oceans.

Figure 8.11: Halophiles, like the Halobacterium shown here, require high salt concentrations. (8)

The **thermophiles** live in extremely hot environments (**Figure** 8.12). For example, they can grow in hot springs, geysers, and near volcanoes. Unlike other organisms, they can thrive in temperatures near 100°C, the boiling point of water!

Methanogens can also live in some strange places, such as swamps, and inside the guts of cows and termites. They help these animals break down cellulose, a tough carbohydrate made by plants (**Figure** 8.13). This would be an example of a mutualistic relationship. Methanogens are named for their waste product, methane, which they make as they use hydrogen gas to reduce carbon dioxide and gain energy. Methane is a greenhouse gas and

Figure 8.12: Thermophiles can thrive in hot springs and geysers, such as this one, the Excelsior Geyser in the Midway Geyser Basin of Yellowstone National Park, Wyoming. (13)

therefore contributes to global warming (see the *Environmental Problems* chapter). Therefore, the rate of methane released in swamps is of interest to scientists studying climate change.

Figure 8.13: Cows are able to digest grass with the help of the methanogens in their gut. (9)

Although archaea are known for living in unusual environments, like the Dead Sea, inside hot springs, and in the guts of cows, they also live in more common environments. For example, new research shows that archaea are abundant in the soil and among the plankton in the ocean. Therefore, scientists are just beginning to discover some of the important roles that archaea have in the environment.

Lesson Summary

- Archaea are prokaryotes that differ from bacteria somewhat in their DNA and biochemistry.
- Most archaea are chemotrophs but some are photosynthetic or form mutualistic relationships.
- Archaea reproduce asexually through binary fission, fragmentation, or budding.
- Archaea are known for living in extreme environments.

Review Questions

1. What domains include the prokaryotes?
2. How are the cell walls of archaea different from those of bacteria?

3. How do archaea obtain energy?
4. How do archaea reproduce?
5. Where do halophiles live?
6. Where do thermophiles live?
7. How did methanogens get their name?
8. Name an example of a mutualistic relationship with archaea.

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- http://en.wikipedia.org/wiki/Archaea

Vocabulary

archaea Single-celled, prokaryotic organisms that are distinct from bacteria.

halophiles Organisms that live and thrive in very salty environments.

methanogens Organisms that live in swamps or in the guts of cows and termites and release methane gas.

thermophiles Organisms that live in very hot environments, such as near volcanoes and in geysers.

Points to Consider

- In the next chapter we will move on to the protists and fungi. How do you think they are different from archaea and bacteria?
- Can you think of some ways that fungi can be helpful?
- Can you think of some ways that fungi can be harmful?

Image Sources

(1) Mom the Barbarian. http://www.flickr.com/photos/momthebarbarian/2441500/. CC-BY 2.0.

(2) NIAID, NIH. http://en.wikipedia.org/wiki/File:EscherichiaColi_NIAID.jpg. Public Domain.

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(4) http://commons.wikimedia.org/wiki/Image:Arkea.jpg. GNU-FDL.

(5) http://commons.wikimedia.org/wiki/File:Average_prokaryote_cell-_en.svg. Public Domain.

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(10) NOAA. *Bluegreen_algae.jpg* . Public Domain.

(11) *Bacilli_division_diagram.png* . GNU-FDL.

(12) *Growing_colony_of_E._coli.jpg* . GNU-FDL.

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Chapter 9

Protists and Fungi

9.1 Lesson 9.1: Protists

Lesson Objectives

- Explain why protists cannot be classified as plants, animals, or fungi.
- List the similarities that exist between most protists.
- Identify the three subdivisions of the organisms in the kingdom Protista.

Check Your Understanding

- What are some basic differences between a eukaryotic cell and a prokaryotic cell?
- List some characteristics that all cells have.

Introduction

So what's a protist? Is it an animal or plant? **Protists** are organisms that belong to the kingdom Protista. These organisms, all **eukaryotes** and mostly **unicellular,** do not fit neatly into any of the other kingdoms. You can think about protists as all eukaryotic organisms that are neither animals, nor plants, nor fungi. Even among themselves, they have very little in common – very simple structural organization and a lack of specialized structures are all that unify them as a group. Although the term *protista* was coined by Ernst Haeckel in 1866, the kingdom Protista was not an accepted classification in the scientific world until the 1960s.

What are Protists?

These unique and varied organisms demonstrate such unbelievable differences that they are sometimes called the "junk drawer kingdom". This kingdom contains the eukaryotes that cannot be classified into any other kingdom. Most protists, such as the ones shown in (**Figure** 9.1), are so tiny that they can be seen only with a microscope. Protists are mostly unicellular eukaryotes that exist as independent cells.However, a few protists are multicellular and surprisingly large.The protists that do form colonies (are multicellular) do not, however, show cellular specialization or differentiation into tissues. Cellular specialization is a major feature of multicellular organisms absent in these protists. For example, kelp is a multicellular protist and is over 100-meters long.

A few characteristics unify the protists:

1. they are eukaryotic which means they have a nucleus
2. most have mitochondria
3. many are parasites
4. they all prefer aquatic or at least moist environments.

For classification, the protists are divided into three groups: animal-like protists, plant-like protists, and fungi-like protists. But remember they are not animals or plants or fungi, they are protists ((**Figure** 9.2)). As there are many different types of protists, the classification of protists can be difficult. Recently, molecular analysis has been used to confirm evolutionary relationships among protists. These molecular studies compare DNA sequences. Protists with higher amounts of common DNA sequences are evolutionarily closer related to each other. Protists are widely used in industry and in medicine.

Protists Obtain Food

Protists need to perform the necessary cellular functions to stay alive. These include the need to grow and reproduce, the need to maintain homeostasis, and the need for energy. So they need to obtain food to provide the energy to enable these functions.

So how are animal-like, plant-like, and fungi-like protists distinguished from each other? Mainly through how they get their carbon. Of course, carbon is essential in the formation of organic compounds: carbohydrates, lipids, proteins, and nucleic acids. You get it from eating, as do other animals.

For such simple organisms, protists get their food in a complicated process. Although there are many photosynthetic protists (such as the algae discussed in the Plant-like Protists section below) that get their energy from sunlight, many others still must swallow their food through a process like endocytosis. Endocytosis was discussed in the *Cell Functions* chapter.

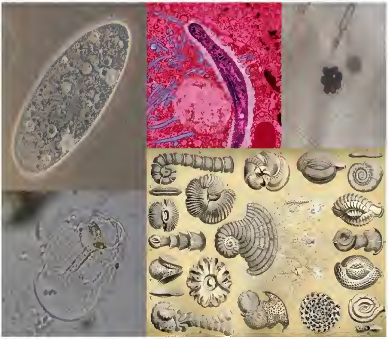

Figure 9.1: Protists come in many different shapes. (11)

Figure 9.2: This slime mold is a protist. Slime molds had previously been classified as fungi but are now placed in the kingdom Protista. Slime molds live on decaying plant life and in the soil. (7)

When a protist is ready to eat, it will wrap its cell wall and cell membrane around its prey, which is usually bacteria. In doing so, it creates a food vacuole or a sort of "food storage compartment." Next the protist produces toxins which paralyze its prospective dinner. Once paralyzed, the food material simply moves by force of gravity through the vacuole and into the cytoplasm of the hungry protist. Other protists are parasitic, and absorb nutrients meant for their host, harming the host in the process.

Animal-like Protists

Animal-like protists are called protozoa. **Protozoa** are unicellular eukaryotes that share certain traits with organisms in the animal kingdom. Those traits are mobility and heterotrophy. Animal-like protists are **heterotrophs** which mean they get their carbon from outside sources—in other words, they eat organic materials. Animal-like protists are very tiny measuring only about 0.01–0.5mm. Animal like protists include the zooflagellates, ciliates, and the sporozoans (**Figure** 9.3).

Figure 9.3: Euglena are animal-like protists. Over 1000 species of Euglena exist and are used in industry in the treatment of sewage. (5)

Although most protists obtain nutrition through pinocytosis, some protists literally "eat with their tails". The tail of a protist is a flagellum and these protists are called **flagellates**. Flagellates acquire oxygen and nitrogen by constantly whipping the flagellum back and forth in a process of filter-feeding. The whipping of the flagellum creates a current that brings food into the protist.

A **flagellum** (plural: **flagella**), is a tail-like structure that projects from the cell body of certain prokaryotic and eukaryotic cells, and it usually functions in helping the cell move.

A flagellum is a cellular structure and not an organelle. Prokaryotic cells may also have flagella.

Different Kinds of Animal-like Protists

Are there different types of animal-like protists? How are they distinguished? You can distinguish one from the other based on how they get around or rather, by their method of locomotion. For example, flagellates have long flagella or tails. Flagella rotate in a propeller-like fashion. An example of a flagellate is the *Trypanosoma*, which causes African sleeping sickness. Other protists have what is called a "transient pseudopodia" or a moving fake foot. Here's how it works. The cell surface extends out a membrane and the force of this membrane propels the cell forward. An example of a protist with a pseudopod is the amoeba. Another way to move if you are a protist is by the movement of cilia. The paramecium has cilia that propel it. Cilia are thin, tail-like projections that extend about 5–10 micrometers outwards from the cell body. Cilia beat back and forth, propelling the protist along. A few protists are non-mobile such as the toxoplasma. Protists such as the toxoplasma form **spores** and are known as sporozoans; these protists but do not have any mobility themselves.

Plant-like Protists

Plant-like protists are **autotrophs.** This means that they produce complex organic compounds from simple inorganic molecules using a source of energy such as sunlight. Plant-like protists live in soil, in seawater, on the outer covering of plants, in ponds and lakes (**Figure** 9.4). Protists like these can be unicellular, or multicellular. Some protists, such as kelp live in huge colonies in the ocean. Plant-like protists are essential to the environment; they produce oxygen (a product of photosynthesis) which sustains other organisms and they play an essential role in aquatic food chains. Plant-like protists are classified into a number of basic groups (**Table** (9.1)).

Table 9.1: **Plant-like Protists**

Phylum	Description	Number (approximate)	Example
Chlorophyta	green algae - related to higher plants	7,500	*Chlamydomnas, Ulva, Volvox*
Rhodophyta	red algae	5,000	*Porphyra*
Phaeophyta	brown algae	1,500	*Macrocystis*
Chrysophyta	diatoms, golden-brown algae, yellow-green algae	12,000	*Cyclotella*
Pyrrophyta	dinoflagellates	4,000	*Gonyaulax*

Table 9.1: (continued)

Phylum	Description	Number (approximate)	Example
Euglenophyta	euglenoids	1,000	*Euglena*

Figure 9.4: Red algae are a very large group of protists making up about 5,000–6,000 species. They are mostly multicellular, live in the ocean. Many red algae are seaweeds and help create coral reefs. (1)

Fungus-like Protists

Fungus-like protists are heterotrophs that have cell walls and reproduce by forming spores. Fungus-like protists mostly immobile but some develop movement at some point in their lives. There are essentially three types of fungus-like protists: water molds, downy mildews, and slime molds (**Table** (9.2)). Slime molds represent the characteristics of the fungus-like protists. Most slime mold measure about one or two centimeters, but a few slime molds are as big as several meters. They are often bright colors such as a vibrant yellow. Others are brown or white. Stemonitis is a kind of slime mold which forms small brown bunches on the outside of rotting logs. Physarum polycephalum lives inside rotting logs and is a gooey mesh of yellow "threads" that are a several centimeters long. Fuligo, sometimes called "vomit mold," is a yellow slime mold found in decaying wood.

Table 9.2: **Fungus-like Protists**

Protist	Source of Carbon	Environment	Characteristics
omycetes: water molds (**Figure** 9.6)	decompose remains, parasites of plants and animals	most live in water	Causes a range of diseases in plants; common problem in greenhouses where the organism kills newly emerged seedlings; have been employed as biocontrol agents; includes the downy mildews, which are easily identifiable by the appearance of white "mildew" on leaf surfaces.
Mycetozoa: slime molds (**Figure** 9.5)	dispose of dead plant material, feed on bacteria	common in soil, on lawns, and in the forest commonly on deciduous logs	Includes the cellular slime mold, which involves numerous individual cells attached to each other, forming one large "supercell," essentially a bag of cytoplasm containing thousands of individual nuclei. The plasmodial slime molds spend most of their lives as individual unicellular protists, but when a chemical signal is secreted, they assemble into a cluster that acts as one organism.

Figure 9.5: An example of a slime mold. (6)

Figure 9.6: An aquatic insect nymph attacked by water mold. (2)

Importance of Protists

Earth would be uninhabitable if it were not for the 80 different groups of organisms called protists. Protists produce almost one-half of the oxygen on the planet, decompose and recycle nutrients that humans need to live, and make up a huge portion of the food chain. Many protists are commonly used in medical research. For example, medicines made from protists are used in treatment of high blood pressure, digestion problems, ulcers, and arthritis. Other protists are used in molecular biology and genetics studies. Slime molds are used to analyze the chemical signals used in directing cellular activities. Protists are also valuable in industry. Carrageenan, extracted from red algae, is used as a gel to solidify puddings, ice cream, and candy. Chemicals from other kinds of algae are used in the production of many kinds of plastics.

Lesson Summary

- Protists are highly diverse organisms that belong to the kingdom Protista.
- Protists are divided into three subgroups: animal-like protists, plant-like protists, fungus-like protists.
- Animal-like protists are unicellular eukaryotes that that share certain traits with organisms in the animal kingdom such as mobility and heterotrophy.
- Plant-like protists are unicellular or multicellular autotrophs that live in soil, in seawater, on the outer covering of plants, in ponds and lakes.
- Fungus-like protists, such as water molds, downy mildews, and slime molds, are heterotrophs that reproduce by forming spores.

Review Questions

1. List the unifying characteristics of protists?
2. List two ways that protists obtain food.
3. Describe the characteristics of an animal-like protist.
4. Describe the characteristics of a plant-like protist.
5. Describe the characteristics of a fungi-like protist.
6. Name three kinds of fungi-like protists.
7. Write a convincing essay demonstrating the importance of protists to life on Earth.
8. Imagine that you are a scientist delivering a paper called "Protists: the Junk-Drawer Kingdom" What would you say in your paper to explain your choice of title?

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- http://en.wikipedia.org/wiki

Vocabulary

autotroph Organism that produces complex organic compounds from simple inorganic molecules using a source of energy such as sunlight.

cilia Thin, tail-like projections that extend about 5–10 micrometers outwards from the cell body; beat back and forth, propelling the protist along.

filter-feeding Characteristic of flagellates; acquire oxygen and nitrogen by constantly whipping the flagellum back and forth; creates a current that brings food into the protist.

flagellum A tail-like structure that projects from the cell body of certain prokaryotic and eukaryotic cells, and it usually functions in helping the cell move.

heterotroph Organism which obtains carbon from outside sources.

protist Eukaryotic organism that belongs to the kingdom Protista; not a plant, animal or fungi.

protozoa Animal-like protists

transient pseudopodia A moving fake foot; the cell surface extends out a membrane and the force of this membrane propels the cell forward.

Points to Consider

- Fungi comprise one of the eukaryotic kingdoms. Think about what might distinguish a fungi-like protist from a true fungus?
- Given the vast differences between the protists discussed in this lesson, think about the possibilities of dividing this kingdom into additional kingdoms. How might that division be accomplished? Is that a good idea or would it just lead to confusion?

9.2 Lesson 9.2: Fungi

Lesson Objectives

- Describe the characteristics of fungi.
- Identify structures that distinguish fungi from plants and animals.
- Explain how fungi can be used in industry.

Check Your Understanding

- What is a significant difference between a protist and other eukaryotic organisms?
- What are some of the distinguishing characteristics of fungus-like protists?

Introduction

Ever notice blue-green mold growing on a loaf of bread? Do you like your pizza with mushrooms? Has a physician ever prescribed an antibiotic for you? If so, then you have encountered fungi. Fungi are organisms that belong to the kingdom Fungi (**Figure** 9.7). Our **ecosystem** needs fungi. Fungi help decompose matter and make nutritious food for other organisms. Fungi are all around us and are useful in many ways to the natural world and to humans in industry.

What are Fungi?

If you had to guess, would you say fungus is a plant or animal? Scientists used to debate about which kingdom to place fungi in. Finally they decided that fungi were plants. But they were wrong. Now scientists know that fungi are not plants at all. Fungi are very different from plants. Fungi belong to their own kingdom called the kingdom Fungi.

Plants are autotrophs, meaning that they make their own "food" using the energy from sunlight. Fungi are heterotrophs, which means that they obtain their "food" from outside

Figure 9.7: These many different kinds of organisms demonstrate the huge diversity within the kingdom Fungi. (4)

of themselves. In other words, they must "eat" or ingest their food like animals or many bacteria do.

Yeasts, molds, and mushrooms are all different kinds of fungi (**Figure** 9.8). There may be as many as 1.5 million species of fungi. You can easily see bread mold and mushrooms without a microscope, but most fungi you cannot see. Fungi is either too small to be seen without a microscope or it lives where you cannot see it easily such as deep in the soil, or under decaying logs, or inside plants or animals. Some fungi even live in or on top of other fungi.

Figure 9.8: The blue in this blue cheese is actually mold. (12)

Fungi and Symbiotic Relationships

If it were not for fungi, many plants would go hungry. In the soil fungi grow closely around the roots of plants. Then as they form that close relationship, the plant and the fungus "feed" one another. The plant provides glucose and sucrose to the fungus that the plant makes through photosynthesis which the fungus cannot do. The fungi then provides minerals and water to the roots of the plant. This form of helping each other out is called **mycorrhizal symbiosis.** Mycorrhizal means "roots" and symbiosis means "relationship" between organisms (**Figure** 9.9).

Figure 9.9: This mushroom and tree live in symbiosis with each other. (3)

Lichens

Have you ever seen an organism called a **lichen?** Lichens are crusty, hard growths that you might find on trees, logs, walls, and rocks. Although lichens may not be the prettiest organisms in nature, they are unique. A lichen is really two organisms that live very closely together—a fungus and a bacteria or algae. The cells from the algae or bacteria live inside the fungi. Each organism provides nutrients for the other. Consequently, a lichen is the result of the symbiosis between a fungus and an another organism.

The earliest scientist to study lichens was Beatrix Potter. You might have heard of her as the author and illustrator of the Peter Rabbit stories. Before Beatrix Potter became a famous author, she was a botanist and studied hundreds of different kinds of fungi. She was the first person to explain the symbiotic relationship between bacteria and fungi. She even presented a scientific paper to the British scientific community in 1897.

Fungi and Insects

Many insects have a symbiotic relationship with certain types of fungi. For example, ants and termites grow fungi in underground "fungus gardens" that they create. Then when the

ants or termites have eaten a big meal of wood or leaves, they eat some fungus from their gardens. The fungus helps them digest the **cellulose** in the wood or leaves. The two species are actually dependent on each other for survival. Ambrosia beetles live in the bark of trees. Like ants and termites, they grow fungi inside the bark of trees where they live and use it to help digest their food.

Fungi as Parasites

Although lots of symbiotic relationships help both organisms, sometimes one of the organisms is harmed. When that happens, the organism that benefits and is not harmed is called a parasite. Have you ever heard of Dutch elm disease? In the late 1960s elm trees in the United States began to die. Since then much of the species has been eliminated. The disease was caused by a fungus that acted as a parasite. The fungus that killed the trees was carried by beetles that inoculated the tree with the fungus. The tree tried to stop the growth of the fungus by blocking its own ability to gain water. However, without water the tree soon dies.

Some parasitic fungi cause human diseases such as athlete's foot and ringworm. These fungi feed on the outer layer of warm, moist skin.

Fungi as Predators

It might seem that fungi growing on a tree trunk or a mushroom in your yard are passive and participating in very little activity, but did you know that some fungi are actually hunters? Some fungi trap nematodes. A nematode is a kind of a worm and is often dinner to fungi. These hungry fungi live deep in the soil where they set traps for unsuspecting nematodes by making a circle with their **hyphae.** Hyphae are sort of the "arms and legs" of a fungus; they look like cobwebs and can be sticky. Fungi set out circular rings of hyphae with a lure inside which brings the nematode inside the fungus (**Figure** 9.10).

Fungi are Good Eaters

Fungi can grow fast because they are such good eaters. Fungi have lots of surface area and this large surface area "eats." Surface area is how much exposed area an organism has compared to their overall volume, and in the mushroom for example, most of that surface area is actually underground. They also have special enzymes that they can squirt into their environment which helps them digest large organic molecules. Sort of like how you might cut up your meat or vegetables before eating, fungi "cut up" large molecules such as sugars, proteins, and lipids into smaller molecules. Then the fungi absorb the nutrients into their cells.

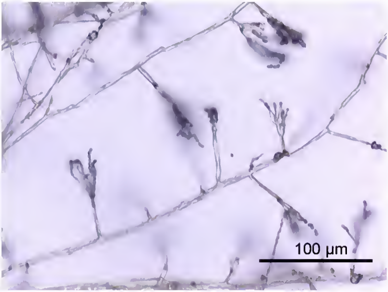

Figure 9.10: Hyphae are the cobwebby arms and legs of fungi. (9)

Fungi Body Parts

Fungi have a cell wall, hyphae, and specialized structures for reproduction. The hyphae are thread-like structures which interconnect and bunch up into **mycelium.** Ever see mold on a damp wall or on old bread? The thing that you are seeing is really mycelia. The hyphae and mycelium help the fungi absorb nutrients from living hosts. Other specialized structures are used in sexual reproduction. One example is a fruiting body. A mushroom is a **fruiting body**, which is the part of the fungus that produces the spores. Spores are the basic reproductive units of fungi.

Fungi Reproduction

Reproduction of fungi is different for different fungi. Many fungi reproduce both sexually or asexually, while some reproduce only sexually and some only asexually. **Asexual reproduction** takes only one parent and **sexual reproduction** takes two parents.

Asexual Reproduction

Fungi reproduce asexually through three methods: spores, budding, and mycelial fragmentation. Asexual spores are formed by the fungi and released to create new fungi. Have you ever seen a puffball? A puffball is a kind of fungus that has thousands of spores in a giant ball. Eventually the puffball bursts and releases the spores in a huge "puff". In budding, the fungus grows part of its body which eventually breaks off. The broken-off piece becomes a

"new" organism. Many fungi can reproduce by mycelial fragmentation or splitting off of the mycelia. A fragmented piece of mycelia can eventually produce a new colony of fungi.

Asexual reproduction is faster and produces more fungi than sexual reproduction. For some species of fungi, asexual reproduction is the only way possible to reproduce. Asexual reproduction is controlled by many different factors, including environmental conditions such as the amount of sunlight and CO_2 the fungus receives, as well as the availability of food.

Sexual Reproduction

Almost all fungi can reproduce with **meiosis.** Meiosis is a type of cell division where haploid cells are produced (discussed in chapter titled *Cell Division, Reproduction and DNA*). But meiosis in fungi is really different from sexual reproduction in plants or animals.

Meiosis occurs in **diploid** cells and is a process that produces **haploid** cells. A diploid cell is a cell with two sets of chromosomes–one from each parent. A haploid cell has one set of chromosomes. In meiosis, the chromosomes duplicate once, and then after two more divisions, four haploid cells are produced. Each haploid cell has half the chromosome number of the parent cell. However, in fungi, meiosis occurs right after two haploid cells fuse, producing four haploid cells. Mitosis then produces a haploid multicellular "adult" organism or haploid unicellular organisms. Mitosis is cell division that results in two genetically identical offspring cells.

Other Sexual Processes

Some species of fungi exchange genetic material by **parasexual** processes. This means that some haploid nuclei in the fungi cells may fuse and form diploid nuclei. These nuclei rarely exist and are usually very unstable. Chromosomes are lost during later mitotic divisions which sometimes makes the offspring fungus genetically different from the parents.

Classification of Fungi

Scientists used to think that fungi were members of the Plant kingdom. They thought this because fungi had several similarities to plants. For example, fungi and plants are usually **sessile** with a leaf or flower that is attached to a stem. Also:

- Both fungi and plants have similar **morphology** or structure.
- Plants and fungi live in the same kinds of habitats, such as growing in soil.
- Plants and fungi both possess a cell wall; animals cells do not have a cell wall.

But scientists now know that fungi are their own separate kingdom — the kingdom Fungi. And that they separated nearly one billion years ago.

Physiological and Morphological Traits

There are a number of characteristics that distinguish fungi from other eukaryotic organisms.

1. Fungi cannot make their own food like plants can since they do not have any of the right equipment for photosynthesis. Fungi are more like animals and some bacteria in that they have to obtain their food from outside sources.
2. The cell walls in lots of species of fungi is **chitin.** Chitin is a nitrogen-containing material that you find in the shells of animals such as beetles and lobsters. But the cell wall of a plant is not made of chitin but rather a carbohydrate called cellulose.
3. Unlike many plants, most fungi do not have a good vascular system. A vascular system is the way that an organism transports fluids such as water and nutrients. In all plant the vascular system is made up of structures called xylem and phloem. But fungi do not have xylem or phloem. This lack of vascular structures distinguishes fungi from plants.
4. However, one characteristic is entirely unique to fungi and does not exist at all in animals or plants. That characteristic is hyphae which combine in groups called mycelium, as described above.

The Evolution of Fungi

Fungi appeared during the Paleozoic Era, a geologic time period lasting from about 570 million to 248 million years ago, and the time when fish, insects, amphibians, reptiles, and land plants appeared. The first fungi were most likely aquatic, and had flagellum that released spores. The first land fungi probably appeared in the Silurian period (443 million years ago to about 416 million years ago), a geologic period during which land plants also appeared.

Roles of Fungi

Fungi are found all over the globe in many different kinds of habitats. Fungi even thrive in deserts. Most fungi however are found on land rather than in the ocean, but some species live only in marine habitats. Fungi are extremely important to these ecosystems because they are one of the major decomposers of organic material in most terrestrial ecosystems. Scientists have estimated that there are nearly 1.5 million species of fungi.

Importance of Fungi for Human Use

Humans use fungi for food preparation or preservation and other purposes. For example, yeasts are required for fermentation of beer, wine and bread (**Figure** 9.11). Some fungi are used in the production of soy sauce and tempeh, a stable source of protein, like tofu, found

in South East Asia. Mushrooms are used in the diet of people all over the globe. Other fungi are producers of antibiotics, such as penicillin. The chitin in the cell walls of fungi, have wound healing properties.

Figure 9.11: Baker's yeast or *Saccharomyces cerevisiae*, a single-cell fungus, is used in the baking of bread and in making wine and beer through fermentation. (8)

Edible and Poisonous Fungi

Some of the best known types of fungi are mushrooms–both edible and poisonous (**Figure** 9.12). Many species are grown commercially, but others must be harvested from the wild. When you order a pizza with mushrooms or add them to your salad, you are most likely eating *Agaricus bisporus*, the most commonly eaten species. Other mushroom species are gathered from the wild for people to eat or for commercial sale.

Have you ever eaten blue cheese? Do you know what makes it blue? You guessed it. Fungus. For certain types of cheeses, producers inoculate milk curds with fungal spores to promote the growth of mold which makes the cheese blue. Molds used in cheese production are safe for humans to eat.

Many mushroom species are poisonous to humans—some mushrooms will simply give you a stomach ache while others may kill you. Some mushrooms you can eat when they are cooked

but are poisonous when raw.

Figure 9.12: Some of the best known types of fungi are the edible and the poisonous mushrooms. (10)

Fungi in the Biological Control of Pests

Some fungi work as natural pesticides. For example in agriculture, some fungi may be used to limit or kill harmful organisms like mites, pest insects, certain weeds, worms, and other fungi that harm or even kill crops.

Lesson Summary

- Fungi are in their own kingdom based on their structures, ways of obtaining food, and on their means of reproduction.
- Fungi live with other organisms in symbiotic relationships.
- Fungi reproduce asexually, sexually and parasexually.
- Fungi appeared during the Paleozoic Era.
- Fungi are widely used in industry and medicine.

Review Questions

1. What two characteristics distinguishes fungi from plants?
2. How many species of fungi exist?
3. Define mycorrhizal symbiosis.
4. Describe the symbiotic relationship of a lichen.
5. How was Beatrix Potter important to the scientific world?
6. Describe the relationship between the ambrosia beetle and fungi?

7. Name two human diseases caused by fungus.
8. When you see mold what body part of the fungus are you observing?
9. Describe asexual reproduction in fungi.
10. Describe sexual reproduction in fungi.

Further Reading / Supplemental Links

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- Webster, Robert and Weber, Roland, *Introduction to Fungi.* Cambridge University Press, 2007.
- Moore-Landecker, Elizabeth, *Fundamentals of Fungi.* Benjamin Cummings, 1996.
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- `http://www.perspective.com/nature/fungi`
- `http://en.wikipedia.org/wiki/Image:DecayingPeachSmall.gif`

Vocabulary

asexual reproduction Reproduction involving only one parent; fungi reproduce asexually through three methods: spores, budding, and mycelial fragmentation.

budding Asexual reproduction in which the fungus grows part of its body which eventually breaks off; the broken-off piece becomes a new organism.

chitin A nitrogen-containing material found in the cell wall of fungi; also found in the shells of animals such as beetles and lobsters.

fruiting body Specialized structure used in sexual reproduction; part of the fungus that produces the spores.

heterotroph Organism which obtains carbon ("food") from outside of themselves.

hyphae Thread-like structures which interconnect and bunch up into mycelium; helps bring food, such as a worm, inside the fungus; : the "arms and legs" of a fungus.

lichen A symbiotic relationship between a fungus and a bacteria or algae; each organism provides nutrients for the other.

meiosis A type of cell division where haploid (one set of chromosomes) cells are produced.

mycelial fragmentation Asexual reproduction involving splitting off of the mycelia; a fragmented piece of mycelia can eventually produce a new colony of fungi.

mycelium Help the fungi absorb nutrients from living hosts; composed of hyphae.

mycorrhizal symbiosis A relationship between fungi and the roots of plants where both benefit; the plant provides glucose and sucrose to the fungus that the plant makes through photosynthesis; the fungi provides minerals and water to the roots of the plant.

parasite The organism that benefits in a relationship between two organisms in which one is harmed.

spores The basic reproductive units of fungi.

Points to Consider

- Plants are fascinating organisms and are widely diverse. Although scientists used to think that fungi were plants, we now know that plants are fungi are separate. In this lesson we have discussed fungi. Now think about what sets plants apart from fungi?

Image Sources

(1) http://en.wikipedia.org/wiki/File:Laurencia.jpg. GNU-FD.

(2) *An aquatic insect nymph attacked by water mold.*. GNU-FDL.

(3) http://en.wikipedia.org/wiki/File:Oudemansiella_nocturnum.JPG. Public Domain.

(4) http://en.wikipedia.org/wiki/Image:Fungi_collage.jpg. CC-BY-SA 2.5.

(5) EPA. http://en.wikipedia.org/wiki/File:Euglena_EPA.jpg. Public Domain.

(6) *An example of a slime mold.*. Public Domain.

(7) http://en.wikipedia.org/wiki/Image:Slime_mold.jpg. GNU-FDL.

(8) http://en.wikipedia.org/wiki/Image:S_cerevisiae_under_DIC_microscopy.jpg. GNU-FDL.

(9) http://en.wikipedia.org/wiki/File:Penicillium.jpg. GNU-FDL.

(10) http://en.wikipedia.org/wiki/Image:Asian_mushrooms.jpg. CC-BY-SA 2.0.

(11) *Protists come in many different shapes.*. GNU-FDL.

(12) *The blue in this blue cheese is actually mold.*. GNU-FDL.

Chapter 10

Plants

10.1 Lesson 10.1: Introduction to Plants

Lesson Objectives

- Describe the major characteristics that distinguish the Plant Kingdom.
- Describe plants' major adaptations for life on land.
- Explain plants' reproductive cycle.
- Explain how plants are classified.

Check Your Understanding

- What are the major differences between a plant cell and an animal cell?
- What is photosynthesis?

Introduction

Plants have adapted to a variety of environments, from the desert to the tropical rain forest to our lakes and oceans. In each environment, plants have become crucial to supporting animal life. First, plants provide animals with food. In a forest, for example, caterpillars munch on leaves while birds eat berries and deer eat grass. Furthermore, plants make the atmosphere friendly for animals. Plants absorb animals' "waste" gas, carbon dioxide, and release the oxygen all animals need for cellular respiration. Finally, plants provide cover and shelter for animals. A bird can take refuge from predators in a shrub and use twigs to make a nest high in a tree (**Figure** 10.1). Without plants, animals would not be able to survive.

Figure 10.1: These bird eggs are benefiting from the cover of a plant; plant materials make up the nest, and when the eggs hatch, the young birds will eat plant products like seeds and berries. (33)

What Are Plants?

From tiny mosses to extremely large trees (**Figure** 10.2), the organisms classified into the Plant Kingdom have three main distinguishable features.

They are all:

- eukaryotic
- photosynthetic
- multicellular

Recall that eukaryotic organisms also include animals, protists, and fungi; eukaryotic cells have true nuclei that contain DNA and membrane-bound organelles such as mitochondria. As discussed in the *Cell Functions* chapter, photosynthesis is the process by which plants capture the energy of sunlight and use carbon dioxide from the air to make their own food. Lastly, plants must be multicellular. Recall that some protists, like diatoms, are eukaryotic and photosynthetic; however, diatoms are not considered plants. Diatoms are a major group of algae, and are mostly unicellular.

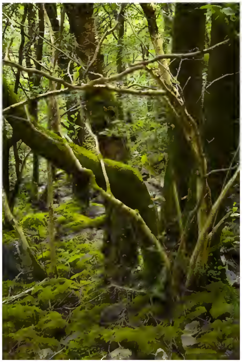

Figure 10.2: There is great diversity in the plant kingdom, from tiny mosses to huge trees. (12)

Adaptations For Life On Land

Much evidence suggests that plants evolved from freshwater green algae (**Figure** 10.3). For example, green algae and plants both have the carbohydrate cellulose in their cell walls and they share many of the same pigments. (For a review of plant cells, see the *Cells and Their Structures* chapter.) So what separates green algae, which are protists, from green plants?

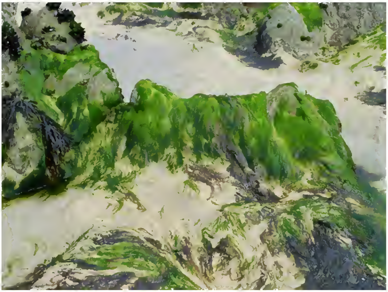

Figure 10.3: The ancestor of plants is green algae. This picture shows a close up of algae on the beach. (11)

One of the main features that distinguishes plants from algae is the retention of the embryo during development. In plants, the embryo develops and is nourished in the female reproductive structure after fertilization. Algae do not retain the embryo. This was the first feature to evolve that separated the plants from the green algae. Plant reproduction will be discussed in the following section.

Although the retention of the embryo is the only adaptation shared by all plants, over time other adaptations for living on land also evolved. In early plants, a waxy layer called a **cuticle** evolved to help seal water in the plant and prevent water loss. However, the cuticle also prevents gases from entering and leaving the plant easily. Recall that the exchange of gasses - taking in carbon dioxide and releasing oxygen - occurs during the process of photosynthesis. Therefore, along with the cuticle, small pores in the leaves called **stomata** also evolved (**Figure** 10.4). The stomata can open and close depending on weather conditions; when it's hot and dry the stomata can stay closed to conserve water. The stomata can open again to permit gas exchange when the weather cools down.

A later adaption for life on land was the evolution of vascular tissue. **Vascular tissue** is specialized tissue that transports water, nutrients, and food in plants. In algae, vascular

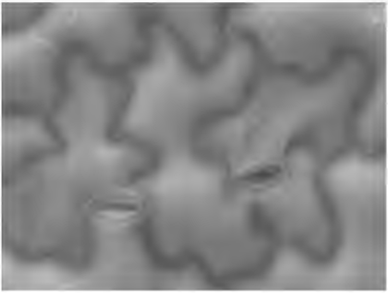

Figure 10.4: Stomata are pores in leaves that allow gasses to pass through, but they can be closed to conserve water. (1)

tissue is not necessary since the entire body is in contact with the water. But on land, water may only be present deep in the ground. Vascular tissue delivers water and nutrients from the ground up and food down into the rest of the plant. The two vascular tissues are xylem and phloem. **Xylem** is responsible for the transport of water and mineral nutrients from the roots throughout the plant. It is also used to replace water lost during transpiration and photosynthesis. **Phloem** mainly carries the sugars made during photosynthesis to the parts of the plant where it is needed.

Plant Reproduction and Life Cycle

Alteration of generations describes the lifecycle of a plant (**Figure** 10.5). In alternation of generations, the plant alternates between a **sporophyte** that has two sets of chromosomes (diploid) and a **gametophyte** that has one set of chromosomes (haploid). Briefly, alternation of generations can be summarized in the following four steps: follow along in **Figure** 10.5 as you read through the steps.

1. The gametophyte produces the **gametes,** sperm and egg, by mitosis. Remember, gametes are haploid.
2. Then the sperm fertilizes the egg, producing a diploid zygote that develops into the sporophyte.
3. The sporophyte produces haploid spores by meiosis.
4. The haploid spores undergo mitosis, developing into the gametophyte.

As we will see in the following lessons, the generation in which the plant spends most of its lifecycle differs between various plants. In the plants that first evolved, the gametophyte takes up the majority of the lifecycle of the plant. During the course of evolution, the sporophyte became the major stage of the lifecycle of the plant. In flowering plants, the female gametophyte is retained within the sporophyte and the male gametophyte is the pollen.

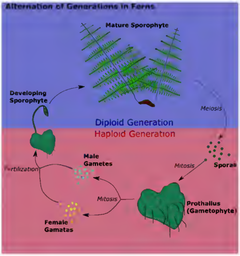

Figure 10.5: In ferns, the sporophyte is dominant and produces spores that germinate into a gametophyte; after fertilization the sporophyte is produced. Ferns will be discussed in further detail in the next lesson. (2)

Classification of Plants

The Plant Kingdom is formally divided into 12 phyla, and these phyla are subdivided into four groups:

1. nonvascular plants
2. seedless vascular plants
3. nonflowering plants
4. flowering plants

Portrayed in **Figure** 10.6 are some of the rich diversity of this kingdom. These four groups are based on the evolutionary history of significant features in plants. The first significant feature to evolve in the Plant Kingdom, after the retention of the embryo, was vascular tissue. Vascular tissue allowed the transport of water and food throughout the plant. The phyla that were around before the evolution of the vascular tissue are known as the **nonvascular plants** (without vascular tissue to move water, nutrients and food). The next significant step

in the evolutionary history of plants was the development of the seed. Plants that evolved vascular tissue but do not have seeds are the **seedless vascular plants.** The final major evolutionary event in the Plant Kingdom was the evolution of flowers and fruits. Plants with vascular tissue and seeds but without flowers are the **gymnosperms.** The plants that have all these features and also fruits and flowers are the **angiosperms.** These four groups are the focus of the next two lessons.

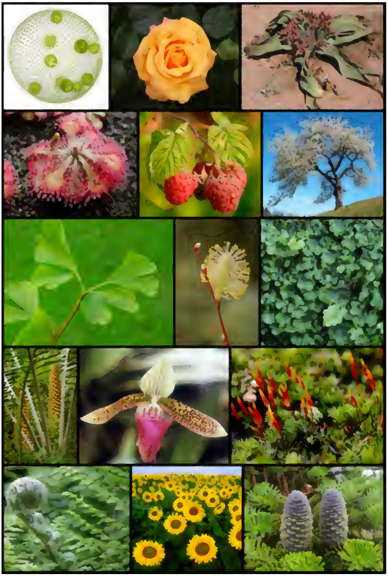

Figure 10.6: The plant kingdom contains a diversity of organisms. Note that *Volvox* in the upper left is a protist, not a plant. (9)

Lesson Summary

- Plants are multicellular photosynthetic eukaryotes that evolved from green algae.
- Plants have several adaptive features for living on land, including a cuticle, stomata, and vascular tissue.
- Plants are informally divided into four groups: the nonvascular plants, the seedless vascular plants, the nonflowering plants (gymnosperms) and the flowering plants (angiosperms).

Review Questions

1. How are plants necessary for animal life?
2. Compare and contrast a typical plant to a photosynthetic protist like a diatom.
3. Plants evolved from green algae. How are they different from green algae?
4. What strategies have plants evolved for life on land?
5. What is the purpose of the stomata?
6. What term describes the plant life cycle?
7. What is the diploid stage of the alteration of generations?
8. Which generation of the alternation of generations is dominant in early plants?
9. What is the term for plants that lack vascular tissue?
10. What is the term for plants that have flowers and bear fruit?

Further Reading / Supplemental Links

- http://www.ucmp.berkeley.edu/plants/plantae.html
- http://www.bioedonline.org/slides/slide01.cfm?q=%22Plantae%22
- http://www.wisc-online.com/objects/index_tj.asp?objID=BIO804
- http://www.perspective.com/nature/plantae
- http://plants.usda.gov
- http://en.wikipedia.org/wiki

Vocabulary

alteration of generations The plant lifecycle, which alternates between a haploid gametophyte and a diploid sporophyte.

angiosperms Plants that flower and bear fruit.

cuticle Waxy layer that aids water retention in plants.

gamete Haploid sex cell; egg or sperm

gametophyte Haploid generation of the alteration of generations life cycle; produces gametes.

gymnosperms Seed plant where seeds are not enclosed by a fruit.

nonvascular plants Plants that do not have vascular tissue to conduct food and water.

sporophyte Diploid generation of the alteration of generations; produces haploid spores.

stomata Small pores on the underside of leaves that can regulate the passage of gasses and moisture.

vascular tissue Tissues that conduct food, water, and nutrients in plants.

Points to Consider

- Can you think of examples of plants that do not have seeds?
- If a plant does not have seeds, how can it reproduce?

10.2 Lesson 10.2: Seedless Plants

Lesson Objectives

- Name examples of nonvascular seedless plants.
- Name examples of vascular seedless plants.
- Explain the reproduction strategies of seedless plants.
- Describe the ways seedless plants impact humankind.

Check Your Understanding

- What is a plant?
- How are plants classified?

Introduction

What might you think a forest would have looked like millions of years ago? Or tens of millions of years ago? Or hundreds of millions of years ago? Probably very different than today. In this lesson the focus will be on the very first and most ancient plants: the nonvascular

seedless plants and the vascular seedless plants. These plants have had a great impact on all our lives. Over 300 million years ago, during the Carboniferous period, forests looked very different than they do today. Seedless plants grew as tall as today's trees in vast swampy forests (**Figure** 10.7). The remains of these forests formed the fossil fuel coal that we depend on today. Although most of these giant seedless plants are now extinct, smaller relatives still remain.

Figure 10.7: Seedless plants were dominant during the Carboniferous period, as illustrated by this drawing. (30)

Nonvascular Seedless Plants

Since the nonvascular seedless plants lack vascular tissue, they also do not have true roots, stems, or leaves. Remember that vascular tissue moves water, food and nutrients throughout the plant. By definition, roots, stems and leaves must contain vascular tissue. However, nonvascular plants do often have a "leafy" appearance and can have stem-like and root-like structures. These plants must also remain very short in stature due to their lack of ability to conduct nutrients and water up a stem. The appearances of the nonvascular plants vary, however, and they are classified into three phyla: the mosses, the hornworts, and the liverworts.

The **mosses,** phylum Bryophyta, are most often recognized as the green "fuzz" on damp rocks and trees in a forest. If you look closely, you will see that most mosses have tiny stem-like and leaf-like structures. This is the gametophyte stage. Remember from lesson 1 that the gametophyte is haploid. The gametophyte produces the gametes that, after fertilization, develop into the diploid sporophyte. The sporophyte forms a distinctive capsule, called the sporangium, which releases spores (**Figure** 10.8).

Figure 10.8: Sporophytes sprout up on stalks from this bed of moss gametophytes. Notice that both the sporophytes and gametophytes exist at the same time. (31)

The **hornworts,** phylum Anthocerophyta, get their name from their distinctive hornlike sporophytes, and "wort" which comes from the Anglo-Saxon word for herb. The hornlike sporophytes grow from a base of flattened lobes, which are the gametophytes (**Figure** 10.9). They tend to grow in moist and humid areas.

Liverworts, phylum Hepatophyta, have two distinct appearances- they can either be leafy like mosses or flattened and ribbon-like. Liverworts get their name from the type with the flattened bodies which can resemble a liver (**Figure** 10.10). Liverworts can often be found along stream beds.

Vascular Seedless Plants

As their name implies, vascular seedless plants have vascular tissue but do not have seeds. Vascular tissue is specialized tissues which conduct water and nutrients throughout the plant. Vascular tissue allowed these plants to grow much taller than nonvascular plants, forming the ancient swamp forests mentioned previously. Most of these large vascular seedless plants

Figure 10.9: In hornworts, the "horns", the sporophytes are rise up from the leaflike gametophyte. (5)

Figure 10.10: Liverworts with a flattened, ribbon-like body are called thallose liverworts. (8)

are now extinct, but their smaller relatives still remain. Seedless vascular plants include the club mosses, the ferns, the horsetails, and the whisk ferns.

Club mosses, in the phylum Lycophyta, are so named because they can look similar to mosses (**Figure** 10.11). Club mosses are not true mosses, though, because they have vascular tissue. The "club" part of the name comes from club-like clusters of sporangia in some types of club mosses. The resurrection plant is also a club moss. It shrivels and turns brown when it dries out, but then quickly recovers and turns green when watered again.

Figure 10.11: Club mosses can superficially resemble mosses, but they have vascular tissue. (29)

Ferns, in the phylum Pterophyta, are the most common seedless vascular plants (**Figure** 10.12). They typically have large divided leaves called fronds. In most ferns, fronds develop from a curled-up formation called a fiddlehead (**Figure** 10.13). The fiddlehead resembles the curled decoration on the end of a stringed instrument, such as a fiddle. Leaves unroll as the fiddleheads grow and expand. Ferns grow in a variety of habitats, ranging in size from tiny aquatic species to giant tropical plants.

The **horsetails,** the phylum Sphenophyta, have hollow, ribbed stems and are often found in marshes (**Figure** 10.14). Whorls of tiny leaves around the stem make the plant look like a horse's tail, but these soon fall off and leave the photosynthetic hollow stem. The stems are rigid and rough to the touch as they are coated with abrasive silicates. Because of their scratchy texture, these plants were once used as scouring pads for cleaning dishes.

The **whisk ferns,** the phylum Psilophyta, have green branching stems with no leaves, so they resemble a whisk broom (**Figure** 10.15). Another striking feature of the whisk ferns is their spherical yellow sporangia.

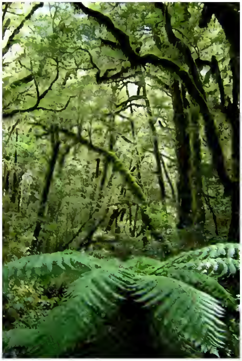

Figure 10.12: Ferns are common in the understory of the tropical rainforest. (14)

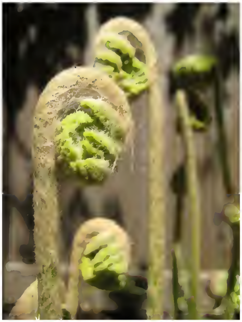

Figure 10.13: The first leaves of most ferns appear curled up into fiddleheads. (23)

Figure 10.14: Horsetails are common in marshes. (20)

Figure 10.15: Whisk ferns have no leaves and bear yellow sporangia. (21)

Reproduction of Seedless Plants

Seedless plants can reproduce asexually or sexually. Some seedless plants, like hornworts and liverworts, can reproduce asexually through fragmentation. When a small fragment of the plant is broken off, it can form a new plant.

Like all plants, nonvascular plants have an alternation of generations lifecycle. In the lifecycle of the nonvascular seedless plants, the gametophyte is dominant. The gametophyte is photosynthetic and normally described as the plant. The male gametophyte produces flagellated sperm that must swim to the egg formed by the female gametophyte. For this reason, sexual reproduction must happen in the presence of water; hence the nonvascular plants tend to live in moist environments. Following fertilization, the sporophyte forms. The sporophyte is connected to and dependent on the gametophyte. The purpose of the sporophyte is to produce spores that will develop into gametophytes and start the cycle over again.

For the seedless vascular plants, the sporophyte tends to be dominant. For example, in ferns the gametophyte is a tiny heart-shaped structure, and the leafy plant we recognize as a fern is the sporophyte (as shown in **Figure** 10.5). The sporangia of ferns are often on the underside of the fronds (**Figure** 10.16). Like the nonvascular plants, ferns also have flagellated sperm that must swim to the egg. But unlike the nonvascular plants, once fertilization takes place, the gametophyte will die and the sporophyte will thrive independently.

Figure 10.16: This fern is producing spores underneath its fronds. (17)

Why Seedless Plants Are Important

The greatest influence of seedless plants on human society was in the formation of the fossil fuel coal millions of years ago. Coal is burned to provide energy. But some seedless plants still have uses in society today. *Sphagnum,* also called peat moss, is commonly used by gardeners to improve soils since it has a great ability to absorb and hold water (**Figure** 10.17). Ferns are also a familiar fixture in many gardens. Besides being prized for their ornamental value, the fiddleheads of certain species of ferns are used in gourmet food. Some species of ferns, like the maidenhair fern, are believed by some people to have medicinal qualities.

Figure 10.17: *Sphagnum,* or peat moss, is commonly added to soil to aid water retention. (3)

Lesson Summary

- Nonvascular seedless plants include mosses, liverworts, and hornworts.
- Vascular seedless plants include club mosses, ferns, whisk ferns, and horsetails.
- Nonvascular seedless plants tend to have a dominant gametophyte while vascular seedless plants tend to have a dominant sporophyte.
- Mosses and ferns are used commonly in gardening.

Review Questions

1. What is vascular tissue?
2. What is an example of a nonvascular seedless plant?
3. What is an example of a vascular seedless plant?

4. Compare and contrast the fern gametophyte and sporophyte.
5. Compare and contrast the whisk fern (Psilophyta) and the ferns (Pterophyta).
6. Compare and contrast mosses and club mosses.
7. What are some uses of the seedless plants to gardeners?
8. What are some of the distinguishing features of horsetails?
9. What does the sporophyte of the hornwort look like?
10. Explain reproduction by fragmentation.

Further Reading / Supplemental Links

- http://www.cavehill.uwi.edu/FPAS/bcs/bl14apl/bryo1.htm
- http://www.microscopy-uk.org.uk/mag/indexmag.html
- http://www.microscopy-uk.org.uk/mag/artjul98/jpmoss.html
- http://www.biologycorner.com/bio2/notes_plants.html
- http://forestencyclopedia.com/p/p1893
- http://www.hiddenforest.co.nz/plants/clubmosses/clubmosses.htm
- http://www.washjeff.edu/greenhouse/Pnudum http://amerfernsoc.org/; http://www.washjeff.edu/greenhouse/Pnudum
- http://en.wikipedia.org/wiki

Vocabulary

club mosses Seedless vascular plants that resemble mosses.

ferns Seedless vascular plants that have large, divided fronds.

hornworts Seedless nonvascular plants with hornlike sporophytes.

horsetails Seedless vascular plants with hollow, rigid stems.

liverworts Seedless nonvascular plants that can have flattened bodies resembling a liver.

mosses Seedless nonvascular plants with tiny stem-like and stem-like structures.

whisk ferns Seedless vascular plants that have branching stems and yellow globular sporangium.

Points to Consider

- Can you think of examples of plants that have seeds?
- Can you think of a plant that has seeds but no flowers or fruits?
- Why do you think having flowers is beneficial to a plant?

10.3 Lesson 10.3: Seed Plants

Lesson Objectives

- Describe the importance of the seed.
- Explain the ways in which seeds are dispersed.
- Define and give examples of Gymnosperms.
- Define and give examples of Angiosperms.
- Explain some uses of seed plants.

Check Your Understanding

- What are the two types of seedless plants?
- How do seedless plants reproduce?

Introduction

If you've ever seen a plant grow from a tiny seed, then you might realize that seeds are rather amazing structures. The seed allows a plant embryo to survive droughts, harsh winters, and other conditions that would kill an adult plant. The tiny plant embryo can simply stay **dormant,** in a resting state, and wait for the perfect conditions for growth before it sprouts. In fact, some seeds can stay dormant for hundreds of years! Another impressive feature of the seed is that it provides stored food for the seedling after it sprouts. This greatly increases the chances that the tiny plant will survive. So being able to produce a seed is a very beneficial adaptation, and as a result, seed plants have been very successful. Although the seedless plants were here on Earth first, today there are many more seed plants than seedless plants. Recall that there are two different groups of seed plants: the Gymnosperms, which do not have flowers or fruits, and Angiosperms, which do have flowers and fruits.

Seeds and Seed Dispersal

For a seed plant species to be successful, the seeds must be dispersed, or scattered out in various directions. If the seed are distributed in a variety of areas, there is a better chance that some of the seeds will find suitable conditions for growth. Furthermore, for plants to establish themselves in new areas, such as areas formed after a glacier retreat, the seeds must somehow reach that new site. To aid with seed dispersal, some plants have evolved special features to encourage their seeds to move long distances.

One such strategy is to allow the wind to carry the seeds. With special adaptations in the seeds, the seeds can be carried long distances by the wind. For example, you might have noticed how the "fluff" of a dandelion moves swiftly in the breeze. Each piece of fluff carries a

seed to a new location. Or if you look under the scales of pine cone, you would see tiny seeds with "wings" that allow these seeds to be carried away by the wind. Maple trees also have specialized fruits with wing-like extensions that aid in seed dispersal, as shown in **Figure** 10.18.

Figure 10.18: Maple trees have fruits with "wings" that help the wind disperse the seeds. (13)

Another common seed dispersal strategy that some flowering plants utilize is to produce a fleshy fruit around the seeds. Animals that eat the seeds aid in the dispersal of the seeds inside. Berries, citrus fruits, cherries, apples, and a variety of other types of fruits are all adapted to be attractive to animals (**Figure** 10.19). Some seeds can pass through an animal's digestive tract unharmed and germinate after they are passed out with the feces.

Some non-fleshy fruits are especially adapted for animals to carry them on their fur. You might have returned from a walk in the woods to find burrs stuck to your socks. These burs are actually specialized fruits that carry seeds to a new location.

Gymnosperms

Plants with "naked" seeds, meaning they are not enclosed by a fruit, are called **Gymnosperms.** Instead, the seeds of Gymnosperms are usually found in cones. There are four phyla of gymnosperms:

1. Coniferophyta, common name conifers

Figure 10.19: Fleshy fruits aid in seed dispersal since animals eat the fruits and carry the seeds to a new location. (26)

2. Cycadophyta, common name cycads
3. Ginkgophyta, Ginkgo trees
4. Gnetophyta, common name gnetophytes

The **Conifers,** members of the phylum Coniferophyta, are probably the gymnosperms that are most familiar to you. The conifers include pines, firs, spruces, cedars, and the coastal redwoods in California that are tallest living vascular plants. The name of this group signifies that the plants bear their reproductive structures in cones, but this is not a characteristic unique to this phylum (**Figure** 10.20). Conifer pollen cones are usually very small, while the seed cones are larger. **Pollen** contains gametophytes that produce the male gamete of seed plants. The pollen, which is a fine to coarse powder-like material, is carried by the wind to fertilize the seed cones (**Figure** 10.21).

The Conifers are important to humankind since they have many uses. They are important sources of lumber and are also used to make paper. Resins, the sticky substance you might see oozing out of a wound on a pine tree, are collected from conifers to make a variety of products, such as the solvent turpentine and the rosin used by musicians and baseball players. The sticky rosin improves the pitcher's hold on the ball or increases the friction between the bow and the strings to help create music from a violin or other stringed instrument.

The **Cycads,** in the phylum Cycadophyta, are also Gymnosperms. They have large, finely-divided leaves and grow as short shrubs and trees in tropical regions. Like the conifers, they produce cones, but the seed cones and pollen cones are always on separate plants (**Figure** 10.22). One type of cycad, the sago palm, is a popular landscape plant. During the Age of

Figure 10.20: A red pine, which bears seeds in cones, is an example of a conifer. (18)

Figure 10.21: The end of a pine tree branch bears the male cones that produce the pollen. (4)

the Dinosaurs (about 65 to 200 million years ago) the cycads were the dominant plants. So you can imagine dinosaurs grazing on cycad seeds and roaming through cycad forests.

Figure 10.22: Cycads bear their pollen and seeds in cones on separate plants. (28)

Ginkgo trees, in the phylum Ginkgophyta, are unique because they are the only species left in the phylum, although there are many other species in the fossil record that have gone extinct (**Figure** 10.23). Therefore, the Ginkgo tree is sometimes considered a "living fossil". The Ginkgo tree survived as it was widely cultivated in China, especially around Buddhist temples. The Ginkgo tree is also a popular landscape tree today in American cities because it is very tolerant of pollution. The Ginkgo tree, like the cycads, has separate female and male plants. The male trees are usually preferred for landscaping because the seeds produced by the female plants smell rather foul as they ripen.

The **Gnetophytes,** in the phylum Gnetophyta, are a very small and unusual group of plants. *Ephedra* is an important member of this group since this desert shrub produces the ephedrine used to treat asthma and other conditions. *Welwitschia* produces extremely long leaves and is found in the deserts of southwestern Africa (**Figure** 10.24). Overall, there are about 70 different species in this very diverse phylum.

Angiosperms

Angiosperms, in the phylum Anthophyta, are the most successful phylum of plants and vastly outnumber the individuals in other phyla (**Figure** 10.25). The feature that distinguishes the angiosperms is the evolution of the flower, so they are also called the flowering plants. Angiosperms inhabit a variety of environments; a water lily, an oak tree, and a barrel cactus are all angiosperms.

Figure 10.23: Ginkgo trees are gymnosperms with broad leaves. (10)

Figure 10.24: One type of gnetophyte is *Welwitschia*. (7)

Figure 10.25: Angiosperms are the flowering plants. (16)

Even though flowers may differ widely in their appearance, they do have some structures in common. The outermost structure is the **sepals,** collectively known as the **calyx,** which are usually green and protect the flower before it opens. The petals, collectively known as the **corolla,** are often bright and colorful to attract a particular pollinator, an animal that carries pollen from one flower to another. The next structure is the **stamens,** consisting of the stalk-like **filament** that holds up the **anther,** or the pollen sacs. The pollen is the male gametophyte. At the very center is the **carpel,** which is divided into three different regions: the sticky, knob-like **stigma** where the pollen lands, the slender tube of the **style,** and the enlarge base known as the **ovary.** The ovary is where the ovules, the female gametophytes, are found. When the ovules are fertilized, the ovule becomes the seed and the ovary becomes the fruit. Some flowers have all these parts and are known as **complete flowers** (**Figure** 10.26), while others may be missing one or more of these parts and are known as **incomplete flowers.**

Table 10.1:

Flower part	Definition
sepals	Outermost layer of the flower that is usually leaf-like and green.
calyx	The sepals collectively; outermost layer of the flower.
corolla	The petals of a flower collectively.
stamens	The part of the flower consisting of a filament and an anther that produces pollen.

Table 10.1: (continued)

Flower part	Definition
filament	Stalk that holds up the anther.
anther	The pollen-containing structure in a flower.
carpel	"Female" portion of the flower; consists of stigma, style, and ovary.
stigma	The knob-like section of the carpel where the pollen must land for fertilization to occur.
style	Slender tube that makes up part of the carpel.
ovary	Enlarged part of the carpel where the ovules are contained.

(*Source:* Jessica Harwood, *License:* CC-BY-SA)

Many plants can self-pollinate, meaning that pollen falls on the stigma of the same flower. Cross-fertilization is often favored and occurs when the pollen from an anther is transferred to a stigma of another flower on another plant. This can be accomplished two ways, by wind or by animals. Flowers that are pollinated by animals such as birds, butterflies, or bees are often colorful and provide nectar, a sugary reward, for their animal pollinators.

Angiosperms are important to humankind in many ways, but the most significant role of angiosperms is as food. Wheat, rye, corn, and other grains are all harvested from flowering plants. Starchy foods, such as potatoes, and legumes, such as beans, are also angiosperms. And as mentioned previously, fruits are a product of angiosperms to increase seed dispersal and are also nutritious foods. There are also many non-food uses of angiosperms that are important to society; for example, cotton and other plants are used make cloth, and hardwood trees to make lumber. The flowering plants are dominant in the environment and are important resources for humans and all animals.

Lesson Summary

- Seeds consist of a dormant plant embryo and stored food.
- Seeds can be dispersed by wind or by animals that eat fleshy fruits.
- Gymnosperms, seed plants without flowers, include the Conifers, the Cycads, the Gingko tree, and the Gnetophytes.
- Angiosperms are flowering plants.
- Seed plants provide many foods and products for humans.

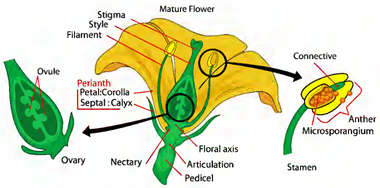

Figure 10.26: A complete flower has sepals, petals, stamens, and one or more carpels. (32)

Review Questions

1. Why are seeds an adaptive feature for seed plants?
2. What is the purpose of a plant developing a fruit?
3. What are two ways that plants disperse their seeds?
4. How do Gymnosperms and Angiosperms differ?
5. What are some examples of Gymnosperms?
6. What are some uses that seed plants have for humans?
7. Firs, spruces, and pines belong to what group of Gymnosperms?
8. Why is the Ginkgo tree considered a "living fossil"?
9. Where is the pollen stored in a flower?
10. How are plants pollinated?

Further Reading / Supplemental Links

- http://home.manhattan.edu/~frances.cardillo/plants/intro/plantmen.html
- http://www.ucmp.berkeley.edu/seedplants/seedplants.html
- http://hcs.osu.edu/hcs300/gymno.htm
- http://biology.clc.uc.edu/Courses/bio106/gymnospr.htm
- http://www.biologie.uni-hamburg.de/b-online/e02/02d.htm
- http://home.manhattan.edu/~frances.cardillo/plants/intro/plantmen.html
- http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookflowers.html
- http://en.wikipedia.org/wiki

Vocabulary

angiosperms Another name for flowering plants.

anther The pollen-containing structure in a flower.

calyx The sepals collectively; outermost layer of the flower.

carpel "Female" portion of the flower; consists of stigma, style, and ovary.

complete flowers Flowers that contain all four structures: sepals, petals, stamens, and one or more carpels.

conifers Group of gymnosperms that bear cones; includes spruces, pine, and fir trees.

corolla The petals of a flower collectively are known as the corolla.

dormant Halting growth and development temporarily.

ginkgo Tree known as the "living fossil" because it is the only species left in the phylum Ginkgophyta.

gnetophytes Diverse group of gymnosperms that includes Ephedra and Welwitschia.

gymnosperms Seed plants in which the seeds are not encased in a fruit.

incomplete flowers Flowers that are missing one or more structures: sepals, petals, stamens, or carpels.

ovary Enlarged part of the carpel where the ovules are contained.

sepals Outermost layer of the flower that is usually leaf-like and green.

stamens The part of the flower consisting of a filament and an anther that produces pollen.

stigma The knoblike section of the carpel where the pollen must land for fertilization to occur.

Points to Consider

- Do you think plants can sense their environment? Why or why not?
- Can you think of an example of a hormone?
- Do you think that plants have hormones?
- How do you think trees know when it's time to lose their leaves?

10.4 Lesson 10.4: Plant Responses

Lesson Objectives

- List the major types of plant hormones and the main functions of each.
- Define tropism and explain examples of tropisms.
- Explain how plants detect the change of seasons.

Check Your Understanding

- Why do pants need sunlight?

Introduction

Plants may not move, but that does not mean they don't respond to their environment. Plants are constantly responding to their surroundings. Plants detect and respond to stimuli such as gravity, light, touch, and seasonal changes. For example, you might have noticed how a house plant bends towards a bright window. Plants must be able to detect and respond to changes in the direction of light. You probably also have noticed that some trees lose their leaves in the autumn, so plants must be able to detect the time of year. Plants are able to respond to stimuli through the help of special chemical messengers, called **hormones.** The various ways that plants respond to their environment and the hormones that control these responses will be the focus of this section.

Plant Hormones

In order for plants to respond to the environment, their cells must be able to communicate with other cells. The chemical signals that travel through cells to help them communicate are called hormones. You might be familiar with the term hormones since animals, including humans, also depend on hormones, such as testosterone or estrogen, to carry messages from cell to cell. Animal hormones will be discussed in the *Controlling the Body* chapter. In both plants and animals, hormones travel from cell to cell in response to a stimulus and also activate a specific response.

Table 10.2: **Each plant hormone has a specific function.**

Hormone	Function
Ethylene	Fruit ripening and abscission
Gibberellins	Break the dormancy of seeds and buds; promote growth

Table 10.2: (continued)

Hormone	Function
Cytokinins	Promote cell division; prevent senescence
Abscisic Acid	Close the stomata ; maintain dormancy
Auxins	Involved in tropisms and apical dominance

(*Source:* Jessica Harwood, *License:* CC-BY-SA)

Ethylene is the plant hormone involved in ripening fruit and with **abscission,** the dropping of leaves, fruits and flowers. When a flower is done blooming or a fruit is ripe and ready to be eaten, ethylene stimulates the production of enzymes that allow the petals or fruit to separate from the plant (**Figures** 10.27 and 10.28). Ethylene is an unusual plant hormone because it is a gas. That means it can move through the air, and a ripening apple can cause another to ripen, or even over-ripen. That's why one rotten apple spoils the whole barrel!

Figure 10.27: The hormone ethylene is signaling these tomatoes to ripen. (25)

Gibberellins are growth-promoting hormones. When gibberellins are applied artificially to plants, the stems grow longer. Therefore, gibberellins can be used in horticulture to increase the growth of ornamental plants, whereas dwarf plants have low concentrations of gibberellins (**Figure** 10.29). Another function of gibberellins is to break the dormancy of

Figure 10.28: The hormone ethylene plays a role in signaling these flower petals to separate and drop, a process known as abscission. (24)

seeds and buds. Gibberellins signal that it's time for a seed to germinate or for a bud to open.

Figure 10.29: Dwarf plants like this bonsai tree often have unusually low concentrations of gibberellins. (22)

Cytokinins are hormones that promote cell division. Cytokinins were discovered from attempts to grow plant tissue in artificial media (**Figure** 10.30). Cytokinins also prevent **senescence,** the programmed aging process. As a result, florists sometimes apply cytokinins

to cut flowers.

Figure 10.30: Cytokinins promote cell division and are necessary for growing plants in tissue culture; a small piece of a plant is placed in sterile conditions to regenerate a new plant. (15)

Abscisic Acid is misnamed because it was once believed to play a role in abscission (the dropping of leaves, fruits and flowers), but we now know abscission is regulated by ethylene. The actual role of abscisic acid is to close the stomata and maintain dormancy. When a plant is stressed due to lack of water, abscisic acid signals the stomata to close. This prevents excess water loss through the stomata. When conditions are not ideal for a seed to germinate or for a winter bud to put out its leaves, abscisic acid signals for dormancy to continue. When conditions improve, the levels of abscisic acid drop and the levels of gibberellins increase, signaling that is time to break dormancy (**Figure** 10.31).

Auxins are hormones that influence many different processes in plants. Auxins produced at the tip of the plant are involved in apical dominance, preventing the growth of side branches. In **apical dominance** the main central stem of the plant is dominant over other side stems; the main stem grows more strongly than other stems and branches. When the tip of the plant is removed, the auxins are no longer present and the side branches begin to grow. This is why pruning generally will help produce a fuller plant with more branches. Auxins are also involved in tropisms, which will be discussed in the next section.

Tropisms

Plants may not be able to move, but they are able to change their growth in response to a stimulus. Growth toward or away from a stimulus is known as a **tropism.** The ability of a plant to curve its growth in one direction is achieved with the signaling of auxin. The auxin moves to one side of the stem, where it starts a chain of events that elongate the cells on

Figure 10.31: A reduction in levels of abscisic acid allows these buds to break dormancy and put out leaves. (27)

Figure 10.32: These seedlings bending toward the sun are displaying phototropism. (6)

just that one side of the stem. With one side of the stem growing faster than the other, the plant begins to bend.

You might have noticed that plants tend to bend towards the light. This is an example of a tropism where light is the stimulus, known as **phototropism** (**Figure** 10.32). To obtain more light for photosynthesis, it's advantageous for leaves and stems to grow towards the light. On the other hand, roots are either insensitive to light or actually grow away from light. This is advantageous for the roots since their purpose is to obtain water and nutrients from deep within the ground.

A seed often starts out underground in the dark, yet the roots always grow downwards into the earth and not toward the surface. How do the roots know which way is up? **Gravitropism** is a growth towards or away from the pull of gravity. Shoots also exhibit gravitropism, but in the opposite direction. If you place a plant on its side, the stem and new leaves will curve upwards. Again, the hormone auxin is involved in this response. Auxin builds up on the lower side of the stem, elongating this side of the stem and causing it to bend upwards over time.

Plants also have a touch response, called **thigmotropism.** If you have ever seen a morning glory or the tendrils of a bean plant twist around a pole, then you know that plants must be able to detect the pole. Thigmotropism works much like the other tropisms. The plant grows straight until it comes in contact with the pole. Then the side of the stem in contact with the pole grows slower than the opposite side of the stem. This causes the stem to bend around the pole.

Table 10.3: **Tropisms**

Type of Tropism	Stimulus
Phototropism	light
Gravitropism	gravity
Thigmotropism	touch

Seasonal Changes

Along with detecting differences in light or gravity, plants also are able to detect the seasons. Leaves change color and drop each autumn in temperate climates (**Figure** 10.33). Certain flowers, like poinsettias, only bloom during the winter. And in the spring, the winter buds on the trees break open and the leaves start to grow. How do plants detect time of year?

Although you might detect the change of seasons by the change in temperature, this is not the primary way by which plants detect the change of seasons. Plants determine the time of year by the length of the day. Because of the tilt of the Earth, during winter days there are less hours of light than during summer days. That's why during the winter it may start getting dark very early during the evening and even stay dark while you're getting ready for

Figure 10.33: Leaves changing color is a response to the shortened length of the day in autumn. (19)

school the next morning. But in the summer it will be bright early in the morning and the sun may not set until late that night. Plants can detect the differences in day length and respond accordingly. For example, in the fall when the days start to get shorter, the trees sense it is time to begin the process of shedding their leaves.

Lesson Summary

- Plant hormones are chemical signals that regulate a variety of processes in plants.
- A plant tropism is growth towards or away from a stimulus such as light or gravity.
- Many plants undergo seasonal changes after detecting differences in day length.

Review Questions

1. What is the term for dropping fruits, flowers, or leaves?
2. What hormone is involved with fruit ripening?
3. How are hormones involved in seed germination?
4. What hormone is involved in tropisms?
5. What hormones promote cell division?
6. What hormone causes stems to elongate?
7. What is phototropism?
8. How does a tendril wind around a pole?
9. How do plants detect the change in seasons?

10. What are some seasonal responses in plants?

Further Reading / Supplemental Links

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- http://en.wikipedia.org/wiki

Vocabulary

abscisic acid Plant hormone involved in maintaining dormancy and closing the stomata.

abscission The shedding of leaves, fruits, or flowers.

apical dominance Suppressing the growth of the side branches of a plant.

auxin Plant hormone involved in tropisms and apical dominance.

cytokinins Plant hormone involved in cell division.

ethylene Plant hormone involved in fruit ripening and abscission.

gibberellins Plant hormone involved in seed germination and stem elongation.

gravitropism Plant growth towards or away from the pull of gravity.

hormones Chemical messengers that signal responses to stimuli.

phototropism Plant growth towards or away from light.

senescence The programmed process of aging and eventual death.

thigmotropism Differential plant growth in response to contact with an object.

tropism Plant growth response towards or away from a stimulus.

Points to Consider

In the next chapter we will turn our attention to animals.

- List some ways animals are different from plants.
- What characteristics do you think define an animal?
- Can you think of examples of animals that do not have hard skeletons?

Image Sources

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Chapter 11

Introduction to Invertebrates

11.1 Lesson 11.1: Overview of Animals

Lesson Objectives

- List the characteristics that define the animal kingdom.
- Define and give examples of the invertebrates.

Check Your Understanding

- What are the main differences between an animal cell and a plant cell?
- How do animals get their energy?

Introduction

How are animals different from other forms of life? Recall that all animals are eukaryotic, meaning that they have cells with true nuclei and membrane-bound organelles. Another feature that distinguishes animals from animal-like protists is that animals are multicellular, while protists are often unicellular. Because animals are multicellular, animal cells can be organized into tissues, organs, and organ systems. Finally, animals are **heterotrophic**, meaning they must ingest some type of organic matter for nutrition and energy (**Figure** 11.1).

Eukaryotic, multicellular, and heterotrophic are features shared by all the millions of diverse types of animals on earth, from tiny ants and snails to giant whales and grizzly bears. In this chapter we will just focus on the invertebrates, the animals that do not have a backbone of bone or cartilage.

Figure 11.1: Animals are heterotrophs, meaning they must eat to get molecules necessary for their growth and energy. (9)

Classification of Animals

Recall that each kingdom of life, including the animal kingdom, is divided into smaller groups called phyla based on their shared characteristics. For example the phylum Mollusca largely consists of animals with shells like snails and clams. Although modern classification is also based on looking at molecular data, such as DNA sequencing, animals have long been classified in their current phyla largely by their physical characteristics.

One example of a physical characteristic used to classify animals is body symmetry. In **radially symmetrical** organisms, such as sea stars, the body is organized like a circle (**Figure** 11.2). Therefore, any cut through the center of the animal results in two identical halves. Other animals, such as humans and worms, are **bilaterally symmetrical,** meaning their left and right sides are mirror images.

Animals are also often classified by their body structure. For example, segmentation, the repetition of body parts, defines one phylum of worms (**Figure** 11.3). Animals that have a true body cavity, defined as a fluid-filled space, and internal organs are also classified in separate phyla from those animals that do not have a true body cavity. Finally, the structure of the digestive system of animals can also be used as a characteristic for classification. Animals with **incomplete digestive tracts** have only one opening in their digestive tracts, while animals with **complete digestive tract** have two openings, the mouth and anus.

Figure 11.2: Sea stars are radially symmetrical. (3)

Figure 11.3: A segmented body plan defines the phylum that includes the earthworms. (7)

What Are Invertebrates?

Besides being classified into phyla, animals are also often characterized as being invertebrates or vertebrates. This is an informal classification term based on the skeletons of the animals. **Vertebrates** have a backbone of bone or cartilage, while invertebrates have no **backbone**. All vertebrate organisms are in the phylum Chordata, while invertebrates make up several diverse phyla. As seen in **Figure** 11.4, the invertebrates include the insects, the earthworms, the jellyfish, the star fish, and a variety of other animals. In the next lessons we will discuss some of phyla within the animal kingdom that contain invertebrates.

Figure 11.4: Snails are an example of invertebrates, animals without a backbone. (18)

Table 11.1:

Phylum	Examples
Porifera	Sponges
Cnidaria	Jellyfish, corals
Platyhelminthes	Flatworms, tapeworms
Nematoda	Nematodes, heartworm
Mollusca	Snails, clams
Annelida	Earthworms, leeches
Arthropoda	Insects, crabs
Echinodermata	Sea stars, sea urchins

Lesson Summary

- Animals are multicellular, eukaryotic heterotrophs.

- Animals can be classified by both molecular data and physical characteristics such as symmetry.
- Invertebrates are animals without a backbone.

Review Questions

1. What are some key features that define the animal kingdom?
2. What does heterotrophic mean?
3. What defines the invertebrates?
4. What are some examples of invertebrates?
5. What is the difference between radially and bilaterally symmetrical animals?
6. What's an example of a bilaterally symmetrical animal?
7. What are some examples of a radially symmetrical animal?
8. What is a body cavity?
9. What is the difference between an incomplete and complete digestive system?
10. What is segmentation?

Further Reading

- http://animaldiversity.ummz.umich.edu/site/index.html
- http://doe.sd.gov/octa/ddn4learning/themeunits/animals
- http://animals.nationalgeographic.com/animals/invertebrates.html
- http://en.wikipedia.com

Vocabulary

bilaterally symmetrical Body plan in which the left and right side are mirror images.

complete digestive tract A digestive tract that has two openings, the mouth and the anus.

heterotroph Organism that cannot make its own food, so it must ingest some type of organic matter.

invertebrates Animals without a backbone.

incomplete digestive tract A digestive tract that has only one opening.

radially symmetrical A body plan in which any cut through the center results in two identical halves.

segmentation Repetition of body parts or segments.

Points to Consider

- What do you think that jellyfishes and corals have in common?
- Think of some examples of animals that are bilaterally symmetrical, where the left side is a mirror image of the right?

11.2 Lesson 11.2: Sponges and Cnidarians

Lesson Objectives

- Describe the key features of the Sponges.
- Describe the key features of the Cnidarians.
- List examples of the Cnidarians.

Check Your Understanding

- How are animals classified?
- What is an invertebrate?

Introduction

The ocean is home to a variety of organisms. Phytoplankton, tiny photosynthetic organisms that float in the water, make their own food from the energy of the sun. Small aquatic animals, known as zooplankton, and larger animals, such as fish, use phytoplankton as a food source. These animals can in turn be eaten by larger aquatic animals, such as larger fish and sharks.

Among the various types of animals that live in the ocean, the **sponges** and **cnidarians** are important invertebrates. The Sponges are believed to be one of the most ancient forms of animal life on earth. The cnidarians, which include the jellyfish, also are among the oldest and most unusual animals on earth. In this lesson we will discuss the features that make these two types of invertebrates unique from other types of animals.

Sponges

Sponges are classified in the phylum **Porifera**, which derives its name from Latin words meaning "pore bearing." These pores allow the movement of water into the sponges' sac-like bodies (**Figure** 11.5). Sponges pump water through their bodies because they are **sessile filter feeders**, meaning they cannot move and must filter organic matter and tiny organisms out of the water to obtain food.

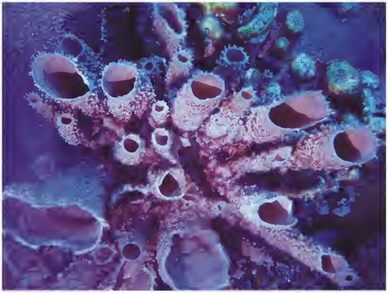

Figure 11.5: Sponges have tube-like bodies with many pores. (11)

Sponges are relatively primitive animals and do not have brains, stomachs, or other organs. In fact, sponges do not even have true tissues. Instead, their bodies are made up of specialized cells that each has specific functions. For example, the collar cells are flagellated and encourage water movement, while other types of cells regulate the water flow by increasing or decreasing the size of the pores.

Cnidarians

The cnidarians, in the phylum **Cnidaria**, include organisms such as the jellyfish (**Figure** 11.6) and sea anemones (**Figures** 11.7 and 11.8) that are found in shallow ocean water. You might recognize that these animals can give you a painful sting if you step on them. That's because cnidarians have stinging cells known as **nematocysts**. When touched, the nematocysts unleash long, hollow threads that are intended to trap prey, and sometimes toxins are also injected through these threads to paralyze the prey.

The body plan of cnidarians is unique because these organisms are radially symmetrical, meaning that they have a circular body plan so that any cut through the center of the animal leaves two equal halves. The cnidarians have two basic body forms, polyp and medusa. The **polyp** is a cup-shaped body with the mouth directed upward, such as a sea anemone (**Figure** 11.8). The **medusa** is a bell-shaped body with the mouth and tentacles directed downward, such as a jellyfish (**Figure** 11.7).

Unlike the sponges, the cnidarians are made up of true tissues. The inner tissue layer secretes digestive enzymes into the **gastrovascular cavity,** a large cavity that has both digestive

and circulatory functions. The cnidarians also have nerve tissue organized into a net-like structure. Cnidarians do not have true organs, however.

Figure 11.6: Jellyfish have bell-shaped bodies with tenticles. (8)

Cnidarian Colonies

Some types of cnidarians are also known to form colonies. For example, the Portuguese man-of-war looks like a single organism but is actually a colony of polyps (**Figure** 11.9). One polyp is filled with air to help the colony float, while several feeding polyps hang below with tentacles full of nematocysts. Consequently, the Portuguese man-of-war is known to cause extremely painful stings to swimmers and surfers who accidentally brush up against these creatures in the water.

Figure 11.7: Sea anemones can sting and trap fish with their tentacles. (15)

Figure 11.8: One type of sea anemone is home to the clownfish. (6)

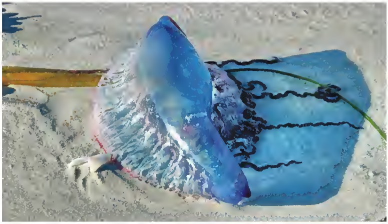

Figure 11.9: The Portuguese man-o-war can deliver debilitating stings with its tentacles. (13)

Coral reefs are built from colonial cnidarians called corals (**Figure** 11.10). The corals are sessile polyps that can extend their tentacles to feed on ocean creatures that pass by. Their skeletons are made up of calcium carbonate, which is also known as limestone. Over long periods of time, their skeletons can accumulate to produce massive structures known as coral reefs. Coral reefs are important habitats for diverse types of ocean life.

Figure 11.10: Corals are colonial cnidarians. (4)

Lesson Summary

- Sponges are sessile filter feeders without true tissues.
- The cnidarians, such as jellyfish, are radially symmetrical with true tissues.
- Colonial cnidarians include the Portuguese man-of-war and corals.

Review Questions

1. What is the only animal to lack true tissues?
2. In what phylum are the sponges?
3. How do sponges gain nutrition?
4. Cnidarians are radially symmetrical. What does this mean?
5. What are some examples of cnidarians?
6. How do cnidarians sting their prey?
7. Describe the nervous system of the cnidarians.
8. How is a jellyfish different from a Portuguese man-o-war?
9. How are coral reefs built?
10. Where are most cnidarians found?

Further Reading / Supplemental Links

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- http://animaldiversity.ummz.umich.edu/site/accounts/information/Porifera.html
- http://en.wikipedia.org/wiki/Cnidaria

Vocabulary

corals Cnidarians that live on ocean reefs in colonies.

cnidarians Invertebrates that have radial symmetry and include the jellyfish.

filter feeders An organism that feeds by filtering organic matter out of water.

gastrovascular cavity A large cavity having both digestive and circulatory functions.

medusa Cnidarian with a bell-shaped body directed downward.

nematocysts Specialized cells in cnidarians that can release a small thread-like structure and toxins to capture prey.

porifera Filter-feeders with sac-like bodies; known as the sponges.

polyp Cnidarian with a cup-shaped body directed upward.

sessile Permanently attached and not freely moving.

Points to Consider

- How do you think that worms are different from sponges and cnidarians?
- How do you think that worms might be similar to sponges and cnidarians?

11.3 Lesson 11.3: Worms

Lesson Objectives

- Describe the major features of the flatworms.
- Describe the major features of the roundworms.
- Describe the major features of the segmented worms.

Check Your Understanding

- In terms of body structure, what does segmentation refer to?
- What is a body cavity?

Introduction

Calling an animal a worm is an informal, non-scientific classification for animals that have long bodies with no appendages. Worms are bilaterally symmetrical, meaning that the right side of their bodies is a mirror of the left. Worms live in a variety of environments, including in the ocean, in fresh water, on land, and as parasites of plants and animals.

In this chapter we will discuss three types of worms: the flatworms, the roundworms, and the segmented worms. These worms are distinguished from each other by their body plan. The flatworms have flat ribbon-like bodies with no body cavity. The roundworms have a body cavity but no segments. The segmented worms have both a body cavity and segmented bodies.

Flatworms

Worms in the phylum **Platyhelminthes** are called flatworms because they have flattened bodies. Some species of flatworms are free live-living organisms that feed on small organisms and decaying matter. These types of flatworms include marine flatworms and fresh-water flatworms such as *Dugesia* (**Figures** 11.11 and 11.12). Other types of flatworms are parasitic and rely on a host organism for energy. For example, **tapeworms** have a modified head region with tiny hooks that help the worm attach to the intestines of a animal host (**Figures** 11.13 and 11.14).

Figure 11.11: *Dugesia* is a type of flatworm with a head region and eyespots. (14)

Flatworms have no true body cavity and an **incomplete digestive system,** meaning that the digestive tract has only one opening. Flatworms do not have a respiratory system, so gas exchange occurs at surface of their bodies. Furthermore, there are no blood vessels or true circulatory system in the flatworms. Their **gastrovascular cavity** serves for both digestion and to distribute nutrients. The flatworms do have a ladder-like nervous system with a distinct head region with a concentration of nerve cells and sensory organs such as eyespots (**Figure** 11.11). The development of a head region, called **cephalization,** arose with the development of bilateral symmetry in animals.

Roundworms

The phylum **Nematoda** includes non-segmented worms known as nematodes or roundworms (**Figure** 11.15). Unlike the flatworms, the roundworms have a body cavity with internal

Figure 11.12: Marine flatworms can be brightly colored. (2)

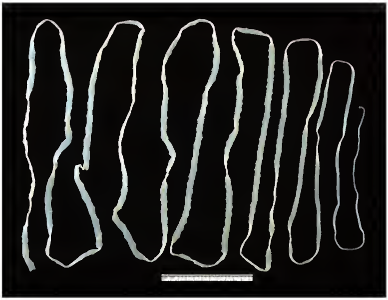

Figure 11.13: Tapeworms are parasitic flatworms that live in the intestines of their hosts. (17)

Figure 11.14: Tapeworms attach to the intestinal wall with a head region that has hooks and suckers. (12)

organs. A roundworm's **complete digestive tract**, meaning the digestive tract includes both a mouth and anus, includes a large digestive organ known as the gut. Roundworms also have a simple nervous system with a primitive brain. Both their anterior and posterior ends have specialized sensory nerves. These nerves are connected with a ventral and dorsal nerve cord that run the length of the body.

Roundworms can be free-living organisms, but they are probably best known for their role as significant plant and animal parasites. The heartworms, which cause serious disease in dogs while living in the heart and blood vessels, are a type of roundworm. Round worms can also cause disease in humans. Elephantiasis, a disease characterized by the extreme swelling of the limbs, is caused by infection with a type of roundworm (**Figure** 11.16).

Segmented Worms

The phylum **Annelida** includes the segmented worms such as the common earthworm, some marine worms, and leeches (**Figures** 11.17 and 11.18). These worms are known as the segmented worms because their bodies are **segmented**, or separated into repeating units. Most segmented worms feed on dead organic matter, while leeches can live in freshwater and suck blood from host organisms. Leeches can also be used medicinally to remove excess blood.

Segmented worms have a well-developed body cavity filled with fluid, which serves as a **hydroskeleton,** a supportive structure that aids in muscle contraction. Segmented worms also tend to have organ systems that are more developed than the roundworms or flatworms. Earthworms, for example, have a complete digestive tract including an esophagus

Figure 11.15: Nematodes can be parasites of plants and animals. (10)

Figure 11.16: One roundworm parasite causes elephantiasis, a disease characterized by the swelling of the limbs. (1)

Figure 11.17: Earthworms are segmented worms. (5)

Figure 11.18: Leeches are parasitic segmented worms. (16)

and intestines. The circulatory system consists of paired hearts and blood vessels, while the nervous system consists of the brain and a ventral nerve cord.

Table 11.2:

Type of Worm	Body Cavity	Segmented	Digestive System	Example
Flatworm	No	No	Incomplete	Tapeworm
Roundworm	Yes	No	Complete	Heartworm
Segmented	Yes	Yes	Complete	Earthworm

(*Source:* Jessica Harwood, *License:* CC-BY-SA)

Lesson Summary

- The flatworms have no true body cavity and include free-living *Dugesia* and parasitic tapeworms.
- The roundworms, which can also be parasitic or free-living, are non-segmented worms with a complete digestive tract and a primitive brain.
- The segmented worms include the common earthworm and leeches.

Review Questions

1. Are all worms classified into a single phylum?
2. Describe the respiratory system of the flatworms.
3. What is cephalization?
4. Name a parasitic flatworm.
5. How does the body plan of the roundworms differ from that of the flatworms?
6. Describe the digestive system of roundworms.
7. What features distinguish Phylum Annelida from the other worms?
8. Describe the skeletal system of a segmented worm.
9. Name a parasitic segmented worm.
10. Earthworms are in what phylum?

Further Reading / Supplemental Links

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- http://en.wikipedia.org/wiki/Annelida

Vocabulary

annelida Invertebrate worms that have segmented bodies, such as earthworms.

cephalization Having a head region with a concentration of sensory organs and central nervous system.

complete digestive tract A digestive tract with two openings, a mouth and anus.

gastrovascular cavity A large cavity having both digestive and circulatory functions.

hydroskeleton Fluid-filled body cavity that provides support for muscle contraction.

incomplete digestive system A digestive tract with only one opening.

nematoda Invertebrate worms that include the roundworms.

platyhelmenthes Invertebrate worms that include the flatworms and tapeworms.

segmentation A body plan that has repeated units or segments.

tapeworms Intestinal parasites in the phylum Platyhelmenthes.

Points to Consider

- How might the vertebrates be different from the invertebrates?
- Can you think of some examples of animals with a backbone?

Lab

Survey of Some Invertebrates

In this lab you will observe some examples of the invertebrates, those animals that do not have a backbone. The hydras are in the phylum Cnidaria. The *Dugesia* are in the phylum Platyhelmenthes, the flatworms. The earthworm is in the phylum Annelida.

Materials:

- compound and dissecting microscopes
- slides and cover slips
- pipettes
- watch glass
- culture of living hydra
- *Dugesia*
- construction paper
- preserved earthworms
- dissection kits

Procedure:

1. **Hydra**
   (a) With a pipette, pull up some of the material from the bottom of the culture dish. Then squeeze a coupe drops onto a clean slide and cover with a cover slip. Observe your hydra under the microscope and sketch one below.
2. **Dugesia**
   (a) With a pipette, place a couple *Dugesia* on a clean watch glass. Observe under the **dissecting** microscope. Sketch below, labeling the eyespots, auricles, and gastrovascular cavity.
   (b) With a dark piece of paper, cover half the watch glass. Do the *Dugesia* seem to prefer the shade or the light? Movement in response to light is called **phytotaxis**.
3. **Earthworm**
   (a) Find the clitellum. What is its function?
   (b) Touch the ventral side of the worm to feel the setae. What are their function?
   (c) Lay the worm on the dissecting tray with the dorsal side up. Using the forceps and the scissors, carefully cut open the worm along a straight line from the clitellum to the mouth. Make sure to just cut the skin so you do not damage the internal organs. Sketch your worm below and label the following: aortic arches, crop, gizzard, pharynx, dorsal blood vessel, intestine, ventral nerve cord, and seminal vesicles.

Image Sources

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(16) Rob and Stephanie Levy. *Leeches are parasitic segmented worms.*. CC-BY 2.0.

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Chapter 12

Other Invertebrates

12.1 Lesson 12.1: Mollusks

Lesson Objectives

- Discuss what characteristics define mollusks.
- Describe the different types of mollusks.
- Explain why mollusks are important.

Check Your Understanding

- What is an invertebrate?
- How are animals classified?

Introduction

Perhaps the best example of a wide variety of attainable mollusks is along a walk on the beach (**Figure** 12.1). There you can find the calcified shells of many different types of mollusks, most typically clams, mussels, scallops, oysters, and snails. Another reminder of the treasures that mollusks yield up may be as close as a jewelry collection (**Figure** 12.2). There glossy pearls, mother of pearl (**Figure** 12.3), and abalone shells reveal some of the unique features of mollusks (**Figure** 12.4).

As you learn about the different types of mollusks and their characteristics, consider how these features help adapt the mollusks to their living conditions. Then also admire their features and see how people's ingenuity has used the mollusk's design and beauty for practical and decorative purposes.

Figure 12.1: The beach yields a wide variety of mollusks. (13)

Figure 12.2: Pearls being removed from oysters. (16)

Figure 12.3: The inside of a bivalve, one of the mollusk classes described in "Types of Mollusks," showing mother of pearl. (35)

Figure 12.4: Shells of marine mollusks, including abalone. (26)

What are Mollusks?

Mollusks belong to the phylum **Mollusca**. The mollusk body is often divided into a head with eyes or tentacles, a muscular foot, and a mass housing the organs. In most species, the muscular foot is used for locomotion. Mollusks also have a mantle, a fold of the outer skin lining the shell, which in most mollusks secretes a calcium carbonate external shell, just like the ones you find on the beach.

The majority of marine mollusks have a gill or gills to absorb oxygen from the water. All species have a complete digestive tract that begins at the mouth and runs to the anus. Many have a feeding structure, the **radula**, found only in mollusks. The radula is composed mostly of **chitin**, a tough, semitransparent substance that is the main component of the shells of crustaceans and the outer coverings of insects. Radulae range from structures used to scrape algae off rocks to the beaks of squid and octopuses.

Larval development suggests a close relationship between the mollusks and other groups, notably the annelids, any of various worms or worm-like animals, including the earthworm and leech, characterized by a cylindrical, elongated, and segmented body. Unlike the annelids, however, mollusks lack body segmentation and their body shape is usually quite different, as well.

The giant squid (**Figure** 12.5), which until recently had not been observed alive in its adult form, is one of the largest invertebrates. However, the colossal squid is even larger and can grow up to 46 ft. (14 m) long. The smallest mollusks are snails that are microscopic in size.

Figure 12.5: The colossal squid, one of the largest invertebrates, here measuring 30 ft (9 m) in length. (21)

Types of Mollusks

Within the phylum Mollusca, there are approximately 160,000 living species and an estimated 70,000 extinct species. Mollusks are typically divided into ten classes, of which two are extinct. Which classes are you most familiar with?

Table 12.1: **Living Molluscan Classes**

Molluscan Class	Number of Species	Habitat	Features of Class/Examples
Caudofoveata	70	Deep ocean	Worm-like organisms
Aplacophora	250	Deep ocean	Worm-like organisms
Polyplacophora	600	Rocky marine shorelines	Chitons (**Figure** 12.6)
Monoplacophora	11	Deep ocean	Limpet-like organisms
Gastropoda	150,000 (80% of living molluscan diversity)	Marine (some limpets live in deep ocean around hot hydrothermal vents), freshwater, and terrestrial	Abalone, limpets, conch, nudibranchs, sea hares, sea butterfly, snails, and slugs (**Figure** 12.7.)
Cephalopoda	786	Marine	Most neurologically advanced of all invertebrates; include squid, octopus, cuttlefish, and nautilus (**Figure** 12.8).

Table 12.1: (continued)

Molluscan Class	Number of Species	Habitat	Features of Class/Examples
Bivalvia	8,000	Marine (some clams live in deep ocean around hot hydrothermal vents) and freshwater.	Most bivalves are **filter feeders** (mechanism whereby suspended matter and food particles are strained from the water, typically by passing the water over a specialized filtering structure); bivalves include clams, oysters, scallops, and mussels.
Scaphopoda	350	Marine	Tusk shells

Figure 12.6: A chiton and sea anemones at a tide pool. (31)

As you can see, the majority of mollusk species live in marine environments, and many of them are found intertidally in the shallow subtidal zone and on the continental shelf. Freshwater species are represented in the bivalves and gastropods, and some gastropods, like land snails, and slugs, live on land.

Figure 12.7: An example of a gastropod species, the ostrich foot. (10)

Figure 12.8: A Caribbean reef squid, an example of a cephalopod. (3)

Importance of Mollusks

Mollusks are important in a variety of ways, including as food, for decoration, in jewelry, and in scientific studies. They are even used as roadbed material and in calcium supplements.

Edible species of mollusks include numerous species of clams, mussels, oysters, scallops, marine and land snails, squid, and octopus. Many species of mollusks, such as oysters, are farmed in order to provide additional food sources (**Figure** 12.9).

Figure 12.9: An oyster harvest in France. (14)

Two natural products of mollusks used for decorations and jewelry are **pearls** and **nacre**, or mother of pearl. A pearl is the hard, round object produced within the mantle of a living shelled mollusk. Fine quality natural pearls have been highly valued as gemstones and objects of beauty for many centuries. The most desirable pearls are produced by oysters and river mussels.

Nacre is an iridescent inner shell layer produced by some bivalves, some gastropods, and some cephalopods, and has been used in sheets on floors, walls, counter tops, doors, and ceilings. It is also inserted into furniture; it can be found in buttons, watch faces, knives, guns, and jewelry; and is used as decorations on various musical instruments.

Several mollusks are ideal subjects for scientific investigation, especially in the area of neurobiology. The giant squid has a sophisticated nervous system and a complex brain for study. The California sea slug, also called the California sea hare, is used in studies of learning and memory, since it has a simple nervous system, consisting of just a few thousand large, easily identified neurons, but also a variety of learning tasks.

Lesson Summary

- The mollusk body often has a head with eyes or tentacles, a muscular foot, a mass housing the organs, and a mantle, which secretes the external shell.
- Other mollusk structures include a gill or gills for absorbing oxygen, a complete digestive tract, and a radula.
- Mollusks are divided into ten living classes, including the familiar gastropods, cephalopods, and bivalves.
- Mollusks live in marine and freshwater habitats, as well as on land.
- Mollusks are important as food, for decoration, and in scientific studies.

Review Questions

1. What are the main characteristics of mollusks?
2. What evidence shows that mollusks and annelids are related? How are they different?
3. What habitats do marine mollusks live in?
4. What makes the California sea slug ideal for studies of learning and memory?
5. Oysters, one of the bivalve filter feeders, filter up to five liters of water per hour. Sediment, nutrients, and algae can cause problems in local waters, but oysters filter these pollutants and either eat them or shape them into small packets that are deposited on the bottom where they are harmless. When there is a high concentration of bacteria in the water from sewage run-off, this can make filter feeders, like clams and mussels, risky to eat. What do you think happens to the pollutants in this case?

Further Reading / Supplemental Links

- http://www.centerofweb.com/scitech/bio_mollusks.htm
- http://www.manandmollusc.net/links_educational.html
- http://www.oceanicresearch.org/education/wonders/mollusk.html
- http://www.manandmollusc.net/links_medicine.html
- http://en.wikipedia.org

Vocabulary

chitin A tough, semitransparent substance that is the main component of the radula.

filter feeders A mechanism whereby suspended matter and food particles are strained from the water, typically by passing the water over a specialized filtering structure.

mollusca The phylum containing ten living classes of mollusks.

nacre The iridescent inner shell layer produced by some bivalves, some gastropods, and some cephalopods; also known as mother of pearl.

pearl The hard, round object produced within the mantle of a living shelled mollusk.

radula A molluscan feeding structure, composed mostly of chitin.

Points to Consider

- Many mollusks demonstrate bilateral symmetry. How do you think this differs from the radial symmetry evident in echinoderms, in the next lesson?
- As we have seen, some species of mollusks live in the deep ocean around hot hydrothermal vents. In the next lesson we will learn that many echinoderms also live in the deep sea. What adaptations do you think both groups might have for living in such a unique environment?
- Mollusks have an exoskeleton, which is primarily external and composed of calcium carbonate. As a result many of these are preserved in the fossil record. How do you think this compares to the type of skeleton that an echinoderm has and to its fossil record?

12.2 Lesson 12.2: Echinoderms

Lesson Objectives

- Discuss the traits of echinoderms.
- List the types of echinoderms.
- Explain the roles echinoderms play.

Check Your Understanding

- What is meant by body symmetry?
- What is radial symmetry?
- What is bilateral symmetry?

Introduction

We're all familiar with starfish (**Figure** 12.10), and also maybe sea urchins (**Figure** 12.11) and sand dollars (**Figure** 12.12). The radial symmetry is what hits us right away, a symmetry in which the body is arranged in five parts around a central axis. Much of the perceived

beauty of this group resides in that design. Later in this lesson, learn how symmetry takes advantage of the animal's habitat.

Figure 12.10: A starfish, showing the radial symmetry, characteristic of the echinoderms. (8)

Figure 12.11: Another echinoderm. a sea urchin, showing its calcareous spines. (33)

The other things that stand out, quite literally, are the calcareous (containing calcium carbonate) spines of the sea urchin. If you've gone snorkeling or walked on a sandy beach you've learned to most likely watch out for those sharp spines. Think about how this adaptation might benefit the sea urchin in terms of predation and colonization by other organisms. Can you think of another use of these structures?

Figure 12.12: An echinoderm, the keyhole sand dollar. (18)

These and other adaptations will be explored in more detail as we examine this most fascinating group of invertebrates. Next time you take a walk on the beach, you'll have appreciation for these organisms and how they are adapted for their environment.

What are Echinoderms?

Echinoderms belong to the phylum **Echinodermata**, which contains marine animals living at all ocean depths. It consists of about 7,000 living species, the largest phylum without freshwater or terrestrial members. Also, few other groups are so abundant in the deep ocean as well as the shallower seas.

As mentioned earlier, echinoderms are radially symmetric. In spite of their appearance, they do not have an external skeleton. Instead, a thin outermost skin covers an internal endoskeleton made of tiny calcified plates and spines, contained within tissues of the organism, and which forms a rigid support. Some groups, such as the sea urchins (**Figure** 12.13), have calcareous spines, referred to earlier, which protect the organism from predation and colonization by encrusting (covering or coating) organisms. The sea cucumbers also use these spines for locomotion.

Echinoderms have a unique **water vascular system**, a network of fluid-filled canals, which function in gas exchange, feeding, and also in locomotion. This system allows them to function without gill slits found in other organisms. Echinoderms possess a very simple

Figure 12.13: An echinoderm, the giant California sea cucumber. (9)

digestive system, often leading directly from mouth to anus. They also possess an open and reduced circulatory system, but no heart. Their nervous system consists of a modified **nerve net** (interconnected neurons with no central brain).

In most species, eggs and sperm cells are released into open water, where fertilization takes place. The release of sperm and eggs is coordinated temporally (to occur at the same time) in some species and spatially (to occur within the same location) in others. Internal fertilization takes place in a few species. Some species even have parental care!

Many echinoderms have amazing powers of regeneration. Some sea stars are capable of regenerating lost arms, and in some cases, lost arms have been observed to regenerate a second complete sea star! Sea cucumbers often discharge parts of their internal organs if they perceive danger. The discharged organs and tissues are then quickly regenerated.

Feeding strategies vary greatly among the different groups of echinoderms. Some are passive filter-feeders, absorbing suspended particles from passing water; others are grazers; others are deposit feeders, which feed on particles of organic matter, usually in the top layer of soil, and still others are active hunters.

Types of Echinoderms

The echinoderms are subdivided into two major groups, the Eleutherozoa, which contains the more familiar, motile classes, and the Pelmatozoa, which contains the sessile (permanently attached and not freely moving) crinoids, including the feather stars (**Figure** 12.14), which have secondarily developed a free-living lifestyle.

Figure 12.14: This passion flower feather star is an echinoderm. (36)

The following table summarizes the four main classes of echinoderms present in the Eleutherozoa Group:

Table 12.2:

Echinoderm Class	Representative Organisms
Asteroidea	Starfish and sea daisies
Ophiuroidea	Brittle stars (**Figure** 12.15)
Echinoidea	Sea urchins and sand dollars
Holothuroidea	Sea cucumbers

Figure 12.15: The giant red brittle star, an ophiuroid echinoderm. (28)

Echinoderms are distributed all over the world at almost all depths, latitudes, and environments in the ocean. They are in highest diversity in reefs but are also widespread on shallow shores, around the poles (where crinoids are at their most abundant) and throughout the deep ocean, where bottom dwelling and burrowing sea cucumbers are common, sometimes

dollar and sea cucumber burrowing provides more oxygen at greater depths of the sea floor, thus allowing a more complex ecological community to develop. In addition, starfish and brittle stars prevent the growth of algal mats on coral reefs, so that the coral can more effectively filter-feed.

Echinoderms are also the staple diet of many organisms, including the otter. Many sea cucumbers provide a habitat for parasites, including crabs, worms, and snails. The extinction of large quantities of echinoderms appears to have caused a subsequent overrunning of ecosystems by seaweed, causing the destruction of entire reefs.

Economically, in some countries echinoderms are regarded as delicacies. Around 50,000 tons of sea urchins are captured each year, and certain parts are consumed mostly in Japan, Peru, and France. Sea cucumbers are considered a delicacy in some southeastern Asian countries.

Some sea cucumber toxins slow down the growth rate of tumor cells, so there is an interest in using these in cancer research. The calcareous external covering of echinoderms is used as a source of lime by farmers in some areas where limestone is unavailable and 4,000 tons of the animals are used each year for this purpose.

Lesson Summary

- Echinoderms belong to the phylum Echinodermata, the largest phylum without freshwater or terrestrial members.
- Echinoderms are radially symmetric, they have an endoskeleton, some have calcareous spines they have a unique water vascular system, a simple digestive system, an open and reduced circulatory system and a modified nerve net.
- Fertilization is generally external; regeneration is fairly common among echinoderms; feeding strategies vary greatly.
- Echinoderms consist of two main subdivisions, the motile Eleutherozoa and the sessile Pelmatazoa.
- Echinoderms are distributed all over the world at almost all depths, latitudes, and marine environments.
- Echinoderms play an important role in the ecological community. Economically, they are eaten as delicacies in different countries, they play a role in cancer research, and they are used as a source of lime.

Review Questions

1. What are the characteristic features of echinoderms?
2. What feeding strategies are represented in the echinoderms?
3. What protection do echinoderms have against predation?
4. Chemical elements within the skeleton makes it stronger and more resistant. How could this be an advantage in grazing echinoderms?

5. The larvae of many echinoderms, especially starfish and sea urchins, are **pelagic** (of or pertaining to the open ocean). How does this relate to the fact that echinoderms are distributed globally?

Further Reading / Supplemental Links

- http://dictionary.reference.com
- http://www.oceanicresearch.org/education/wonders/echinoderm.html
- http://www.junglewalk.com/info/echinoderm-information.htm
- http://invertebrates.si.edu/echinoderm/http://en.wikipedia.org

Vocabulary

echinodermata The phylum of the echinoderms; contains about 7,000 living species, the largest phylum without freshwater or terrestrial members.

nerve net Interconnected neurons that send signals in all directions.

pelagic Of, or pertaining to, the open ocean.

sessile Permanently attached and not freely moving.

water vascular system A network of fluid-filled canals; functions in gas exchange, feeding, and also in locomotion.

Points to Consider

- Echinoderms' water vascular system functions in gas exchange via a network of fluid-filled canals. Terrestrial arthropods have internal surfaces that are specialized for gas exchange, via air sacs. How might these systems compare and differ?

- Echinoderms possess an open and reduced circulatory system, consisting of a central ring and five radial vessels but no heart. Arthropods also have an open circulatory system but the blood is propelled by a series of hearts into the body cavity where it comes in direct contact with the tissues. Why might there be an advantage to having a heart as part of the circulatory system?

12.3 Lesson 12.3: Arthropods

Lesson Objectives

- Explain what arthropods are.
- Describe the features of crustaceans.
- Describe the characteristics of centipedes and millipedes.
- List the features of arachnids.
- Describe why arthropods are important.

Check Your Understanding

- What is an invertebrate?
- What do mollusks and echinoderms have in common?

Introduction

With over a million described species in the phylum containing arthropods, chances are you encounter one of these organisms every day, even without leaving your house. As much as we would like to eliminate all insect pests from our dwellings, for example, there is a great probability you will see an ant, a spider, a fly, or a moth inside. Even if you don't, you will most likely see such creatures in your yard or on a walk around your neighborhood.

Wherever you observe these animals, you will see a tremendous amount of diversity and adaptations. You will also learn, despite how you feel about how annoying some of these organisms may be, how beneficial in fact they are both ecologically and economically.

What are Arthropods?

Arthropods belong to the phylum **Arthropoda**, which means "jointed feet," and includes four living subphyla. These are chelicerates, including spiders (**Figure** 12.16), mites, scorpions (**Figure** 12.17) and related organisms; myriapods, comprising centipedes (**Figure** 12.18) and millipedes (**Figure** 12.19) and their relatives, who are hexapods, including insects and three small orders of insect-like animals; and crustaceans, including lobsters (**Figure** 12.20), crabs (**Figure** 12.21), barnacles (**Figure** 12.22), crayfish (**Figure** 12.23), and shrimp.

Arthropods are characterized by the possession of a segmented body with appendages on at least one segment. Arthropod appendages are used for feeding, sensory reception, defense, and locomotion. Their heart is on the dorsal side and the nervous system on the ventral. They are covered by a hard exoskeleton made of chitin, which provides physical protection and among terrestrial species resistance to drying out. In order to grow, arthropods shed

Figure 12.16: A species of spider in its web. (7)

Figure 12.17: A species of scorpion. (4)

Figure 12.18: A centipede, from the subphyla of myriapods. (34)

Figure 12.19: A species of millipede found in Hawaii. (1)

Figure 12.20: The blue American lobster illustrates the segmented body plan of the arthropods. (22)

Figure 12.21: Giant spider crabs. (25)

Figure 12.22: The sessile barnacles shown here feeding. (32)

Figure 12.23: A crayfish. (27)

this covering in a process called **molting**.

It is the largest phylum in the Animal Kingdom with more than a million described species making up more than 80% of all described living species. They are found commonly throughout marine, freshwater, terrestrial, and even aerial environments, in addition to various forms that are **parasitic** and **symbiotic**. They range in size from microscopic plankton (approximately ¼ mm) up to the largest living arthropod, the Japanese spider crab, with a leg span up to 12 feet (3.5 m).

Aquatic arthropods use gills to exchange gases. These gills have an extensive surface area in contact with the surrounding water. Terrestrial arthropods have internal surfaces that are specialized for gas exchange. Insects and most other terrestrial species have a **tracheal system**, where air sacs lead into the body from pores in the exoskeleton, for oxygen exchange. Others use **book lungs**, or gills modified for breathing air, as seen in species like the coconut crab. Some areas of the legs of soldier crabs are covered with an oxygen absorbing membrane. Terrestrial crabs sometimes have two different structures: one that is gilled, which is used for breathing underwater, and another adapted to take up oxygen from the air.

Arthropods have an open circulatory system with **haemolymph**, a blood-like fluid, which is propelled by a series of hearts into the body cavity where it comes in direct contact with the tissues. Arthropods have a complete digestive system with a mouth and anus.

Crustaceans

The crustaceans are a large group of arthropods, consisting of almost 52,000 species. The majority of them are aquatic, living in either marine or freshwater habitats. A few groups have adapted to living on land, such as terrestrial crabs, terrestrial hermit crabs, and woodlice (**Figure** 12.24).

Crustaceans are among the most successful animals and are as abundant in the oceans as insects are on land. The majority of crustaceans are motile, although a few groups are parasitic and live attached to their hosts. Adult barnacles live a sessile life, where they are attached headfirst to the substrate and cannot move independently.

Various parts of the crustacean exoskeleton may be fused together, such as in the **carapace**, the thick dorsal shield seen in many crustaceans that often forms a protective chamber for the gills. The main body cavity is an expanded circulatory system, through which blood is pumped by a heart located near the dorsal surface. The digestive system consists of a straight tube that often has a gizzard-like **gastric mill** for grinding food and a pair of digestive glands that absorb food.

Structures that function as kidneys are located near the antennae. A brain exists in the form of **ganglia** (connections between nerve cells) close to the antennae and a collection of major ganglia below the gut. Most crustaceans have separate sexes. Many terrestrial crustaceans, such as the Christmas Island red crab, mate seasonally and return to the sea to release the

Figure 12.24: A terrestrial arthropod, a species of woodlice. (20)

eggs. Others, such as woodlice, lay their eggs on land, although in damp conditions. In other crustaceans, the females keep the eggs until they hatch into free-swimming larvae.

Six classes of crustaceans are generally recognized:

Table 12.3:

Class	Information
Branchiopoda	Includes brine shrimp
Remipedia	A small class restricted to deep caves connected to salt water
Cephalocarida	The horseshoe shrimp
Maxillopoda	Includes barnacles and copepods
Ostracoda	Small animals with bivalve shells
Malacostraca	The largest class, with the largest and most familiar animals: crabs, lobsters, shrimp, krill, and woodlice

Centipedes and Millipedes

Centipedes and millipedes belong to the subphylum **Myriapoda**, which contains 13,000 species, all of which are terrestrial, and which are divided among four classes. They range from having over 750 legs (a species of millipede) to having fewer than ten legs. They have a single pair of antennae and simple eyes.

They are most abundant in moist forests, where they help to break down decaying plant material, although a few live in grasslands, semi-arid habitats, or even deserts. The majority are herbivores, but centipedes are chiefly nocturnal predators.

Although not generally considered dangerous to humans, many from this group produce noxious secretions, which can cause temporary blistering and discoloration of the skin. Centipedes are fast, predatory, and venomous. There are around 3,300 described species, ranging

Arachnids

Arachnids are a class of joint-legged invertebrates in the subphylum **Chelicerata**. They are mainly terrestrial, but are also found in freshwater and in all marine environments, except for the open ocean. They comprise over 100,000 named species, including spiders (**Figure** 12.25), scorpions (**Figure** 12.26), daddy-long-legs, ticks, and mites (**Figure** 12.27) and there may be up to 600,000 species in total, including unknown ones.

Figure 12.25: A daddy-long-legs with a captured woodlouse. (24)

It is commonly understood that arachnids have four pairs of legs and that they may be easily distinguished from insects on this basis (insects have three pairs of legs). Arachnids also have two additional pairs of appendages, the first pair, the **chelicerae**, serve in feeding and defense. The next pair, the **pedipalps**, are adapted for feeding, locomotion, and/or reproductive functions. Arachnids are further distinguished by the fact they have no antennae and no wings. Their body is organized into the **cephalothorax**, derived from the fusion of the head and thorax, and the abdomen.

Arachnids are also well adapted for a terrestrial existence. They have internal respiratory surfaces in the form of trachea or a book lung. They also have appendages modified for more efficient locomotion on land, internal fertilization, special sensory organs, and structures for water conservation, such as more efficient excretory structures and a waxy layer covering the outer layer of the exoskeleton.

Arachnids are mostly carnivorous, feeding on the pre-digested bodies of insects and other small animals. Several groups are largely venomous and they secrete venom from specialized glands to kill prey or enemies. Several mites are parasitic and some of those are carriers of disease. Arachnids usually lay eggs, which hatch into immature arachnids that resemble the adults. Scorpions, however, bear live young.

Figure 12.26: Various diseases are caused by species of bacteria that are spread to humans by "hard" ticks, like the one shown here. (12)

Figure 12.27: A female crab spider sharing its flower with velvet mites. (6)

The arachnids are divided into eleven subgroups. **Table** (12.4) shows the four most familiar subgroups, with a description of each.

Table 12.4:

Subgroup of Arachnid	Representative Organisms	Approximate Number of Species	Description
Araneae	Spiders	40,000	Found all over the world, ranging from tropics to the Arctic, some in extreme environments; All produce **silk**, used for many functions, including trapping insects in webs, aiding in climbing, forming smooth walls for burrows, producing egg sacs, and wrapping prey Nearly all spiders inject venom to protect themselves or to kill prey; only about 200 species have bites that can be harmful to humans

Table 12.4: (continued)

Subgroup of Arachnid	Representative Organisms	Approximate Number of Species	Description
Opiliones	Daddy-long-legs	6,300	Known for exceptionally long walking legs; no silk nor poison glands Many are omnivores, eating small insects, plant material and fungi; some are scavengers, eating decaying animal and other matter Mostly nocturnal, colored in hues of brown; a number of diurnal species have vivid patterns of yellow, green, and black

Table 12.4: (continued)

Subgroup of Arachnid	Representative Organisms	Approximate Number of Species	Description
Scorpiones	Scorpions	2,000	Characterized by a tail with six segments, the last bearing a pair of venom glands and a venom-injecting barb Predators of small arthropods and insects, they use pincers to catch prey, then either crush it or inject it with a fast-acting venom, which is used to kill or paralyze the prey; only a few species are harmful to humans Nocturnal; during the day find shelter in holes or under rocks Unlike the majority of arachnids, scorpions produce live young, which are carried about on the mother's back until they have molted at least once; they reach an age of between four to 25 years

Table 12.4: (continued)

Subgroup of Arachnid	Representative Organisms	Approximate Number of Species	Description
Acarina	Mites and ticks	30,000	Most are minute to small (no more than 1.0 mm in length), but some ticks and one species of mite may reach lengths of 10-20 mm Live in nearly every habitat, including aquatic and terrestrial Many are parasitic, affecting both invertebrates and vertebrates, and may be vectors of human and other mammalian disease; those that feed on plants may damage crops

Why Arthropods are Important

Many species of crustaceans, especially the familiar crabs, lobsters, shrimp, prawn, and crayfish, are consumed by humans, and nearly 10,000,000 tons were produced in 2005. Over 70% by weight of all crustaceans caught for consumption are shrimp and prawns, and over 80% is produced in Asia, with China producing nearly half the world's total.

Some mites prey on undesirable arthropods and are used in pest control, while others control weed growth. Populations of whip scorpions are valuable in controlling populations of cockroaches and crickets. Finally, an unquantified, but major positive contribution of the mites and ticks, as well as the centipedes and millipedes, is their role in ecosystems, especially their roles as decomposers and the resulting enriching of the soil due to the release of the nutrients during decomposition.

In the next lesson, we will discuss the diversity of insects. As we will see, insects, also arthropods are beneficial in many ways, both to the ecosystems of which they are part, as well as to humans.

Lesson Summary

- The phylum Arthropoda includes four living subphyla; chelicerates, including spiders, mites, and scorpions; myriapods, including centipedes and millipedes; hexapods, including insects; and crustaceans. Arthropods are characterized by a segmented body; appendages used for feeding, sensory structures, defense, and locomotion; a dorsal heart and a ventral nervous system; and a hard exoskeleton. Arthropods are the largest phylum in the Animal Kingdom with more than a million described species; they are found in all environments. There are a variety of respiratory systems in arthropods, including gills, tracheal system, book lungs, and oxygen absorbing membranes; arthropods have an open circulatory system and a complete digestive system.
- Crustaceans consist of almost 52,000 species, the majority of which are aquatic; they are among the most successful animals. There are six classes of crustaceans, including brine shrimp, barnacles and copepods, and the malacostracans, including crabs, lobsters, and shrimp. Centipedes and millipedes belong to the myriapods, where they occur most abundantly in moist forests; they are chiefly nocturnal predators.
- Arachnids are mainly terrestrial and comprise over 100,000 named species; adaptations for a terrestrial existence include specialized respiratory structures, appendages modified for locomotion on land, internal fertilization, special sensory organs, and structures for water conservation. Arachnids are divided into eleven subgroups, the most familiar being spiders; spiders produce silk, which is used in a variety of ways. Many species of crustaceans are used for food; some species of mites are used in pest control and for controlling weeds; and centipedes, millipedes, and the acarines play a valuable role as decomposers, enriching the soil as a result.

Review Questions

1. What are arthropod appendages used for?
2. What respiratory systems do terrestrial arthropods use?
3. Arachnids have several adaptations for living on land. For each adaptation you list, explain how it is beneficial for a terrestrial existence.

4. How does the scorpions' method of producing young differ from most other arachnids?

Further Reading / Supplemental Links

- http://cybersleuth-kids.com/sleuth/Science/Animals/Arthropods/index.htm
- http://www.oceanicresearch.org/education/wonders/arthropods.htm
- http://www.biokids.umich.edu/critters/Crustacea
- http://www.nps.gov/archive/yell/kidstuff/Alphabet/a.htm

Vocabulary

acarina The group of arachnids containing the mites and ticks.

araneae The arachnid group containing the spiders.

arthropoda The phylum meaning "jointed feet;" includes four living subphyla of arthropods.

book lungs Gills modified for breathing air.

carapace The thick dorsal shield seen in many crustaceans; often forms a protective chamber for the gills.

cephalothorax The anterior part of the arachnid body, derived from the fusion of the head and thorax.

chelicerae The first pair of arachnid appendages; used in feeding and defense.

chelicerata An arthropod subphylum containing the arachnids.

ganglia A compact group of nerve cells having a specific function.

gastric mill A gizzard-like structure for grinding food.

haemolymph A blood-like fluid, which is propelled by a series of hearts into the body cavity, where it comes in direct contact with the tissues.

molting The process by which arthropods shed their hard exoskeleton in order to grow.

myriapoda An arthropod subphylum containing the centipedes and millipedes.

opiliones The arachnid group containing daddy-long-legs.

parasitic Living on or in an organism of another species; harmful to the host species.

pedipalps The second pair of arachnid appendages used for feeding, locomotion, and/or reproductive functions.

scorpiones The group of arachnids containing the scorpions.

silk A thin, strong, protein strand extruded from the spinnerets; most commonly found on the end of the abdomen of spiders.

symbiotic The living together of two dissimilar organisms.

Points to Consider

- Arthropods are characterized by the possession of a segmented body with appendages on at least one segment and they are covered by a hard exoskeleton made of chitin. How is the general arthropod body plan specialized in the insects?
- Insects are the only group of invertebrates to have developed flight. Compare this mode of locomotion to those discussed in the groups of arthropods already discussed. What advantages might there be to using flight for a method of locomotion?

12.4 Lesson 12.4: Insects

Lesson Objectives

- Describe the characteristics of insects.
- Explain how insects obtain food.
- Describe reproduction and the life cycle of insects.
- Explain how insects are important.
- Describe how insect pests are controlled.

Check Your Understanding

- What is an arthropod?
- Is a spider an insect? Why or why not?

Introduction

Insects, with over a million described species, are the most diverse group of animals on Earth. They may be found in nearly all environments on the planet. That would explain that no matter where you travel, you are bound to see representatives from this group and probably lots of different kinds as well. Even if you were not partial to bees, wasps, and ants perhaps, it would be difficult to not admire the beauty of a butterfly, moth, or even a dragonfly!

As you learn about the amazing diversity within this group and some of the fascinating behaviors, you may begin to look upon some of the insects you come upon with a bit more interest! Perhaps you will even learn to appreciate some of the species you may dislike now, such as bees and wasps, when you realize how beneficial they are to humans and especially necessary for the continued presence of some of the beautiful flowers or delicious fruits that may grace your yard or nearby park.

What Are Insects?

Insects are a major group of arthropods and the most diverse group of animals on the planet, with over a million described species and more than half of all known living organisms. They are found in nearly all environments on Earth, although only a few species occur in the oceans. Adults range in size from a minuscule fairy fly to a 21.9 in (55.5 cm) long stick insect (**Figure** 12.28).

Figure 12.28: A stick insect, showing how well it blends in to its environment. (29)

Insects have segmented bodies with an exoskeleton. The outer layer of the exoskeleton, the **cuticle,** is made up of two layers, a thin and waxy water resistant outer layer (the **exocuticle**), and an inner, much thicker layer. The exocuticle is greatly reduced in many soft-bodied insects and especially in larval stages, such as caterpillars (**Figure** 12.29).

The segments of the body are organized into three distinctive but joined units: a head, a thorax, and an abdomen (**Figure** 12.30).

Figure 12.29: Caterpillars feeding on a host plant. (23)

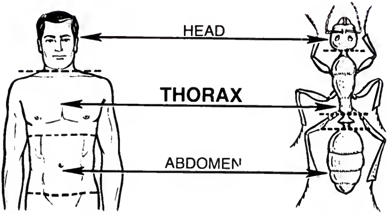

Figure 12.30: A diagram of a human and an insect, comparing the three main body parts: head, thorax, and abdomen. (2)

Table 12.5: **shows the structures present in each body segment.**

Head	Thorax	Abdomen
A pair of sensory antennae, a pair of compound eyes, one to three simple eyes, and three sets of variously modified appendages that form the mouthparts	Six segmented legs and two or four wings	Has most of the digestive, respiratory, excretory, and reproductive structures

The nervous system is divided into a brain and a ventral nerve cord. Air is taken in through the **spiracles**, openings on the sides of the abdomen. Insect respiration occurs without lungs, with a system of internal tubes and sacs through which oxygen is delivered directly to the adjoining body tissues. Since oxygen is delivered directly, the circulatory system is therefore greatly reduced and consists of only a single dorsal tube with openings. The tube pulses and circulates blood-like fluids inside the body cavity.

Insect locomotion includes flight, walking, and swimming. Insects are the only invertebrates to have developed flight and this has played an important role in their success. Insect flight is not very well understood. Primitive insect groups use muscles that act directly on the wing structure. More advanced groups have foldable wings and their muscles act on the wall of the thorax and give power to the wings indirectly. These muscles are able to contract multiple times for each single nerve impulse, allowing the wings to beat faster than would ordinarily happen.

Many adult insects use six legs for walking and have adopted a gait that uses the legs in alternate triangles touching the ground. This gait allows for rapid walking at the same time as having a stable stance. A few insects have evolved to walk on the surface of the water, especially the water striders (**Figure** 12.31).

A large number of insects live either parts of or their whole lives underwater. Water beetles and water bugs have legs adapted to paddle in the water. Dragonfly young use jet propulsion, forcibly expelling water out of the rectal chamber.

Insects use a wide variety of senses for both communicating and receiving information. Many insects have very sensitive and/or specialized sensory organs. **Table** (12.6) summarizes five types of communication that are used by various insects and sometimes for different purposes.

Figure 12.31: A pair of water striders mating, showing how water surface tension allows for them to stand on the water. (17)

Table 12.6: **Insect Communication**

Types of Communication	Representative Organisms	Description
Visual Ultraviolet wavelengths Polarized light Bioluminescence	Bees Bees Fireflies	Perceive ultraviolet wavelengths Detect polarized light Reproduction and Predation Some species produce flashes to attract mates; other species to lure prey.

Table 12.6: (continued)

Types of Communication	Representative Organisms	Description
Sound Production Mostly by mechanical action of appendages Ultrasound clicks Hearing	Cicadas Moths Moths Some predatory and parasitic insects	Loudest sounds among insects; have special modifications of body and musculature to produce and amplify sounds. Predation Produced mostly by unpalatable moths to warn bats; other moths make similar sounds in order to mimic distasteful moths so they will be avoided by bats as well. Predation Some nocturnal species can hear the ultrasonic emissions of bats, which help them avoid predation. Can detect sounds made by prey or hosts.

Table 12.6: (continued)

Types of Communication	Representative Organisms	Description
Chemical Wide range of insects have evolved chemical communication; chemicals often derived from plant metabolites and are used to attract, repel, or provide other kinds of information; chemicals may be targeted at individuals of same or different species; use of scents is especially well developed in social insects.	Moths	Antennae of males can detect **pheromones** (chemicals secreted by animals, especially insects, that influence the behavior or development of others within the same species) of female moths over distances of many kilometers (**Figure** 12.32).
Infrared	Blood-sucking insects	Have specialized sensory structures that can detect infrared emissions in order to find their hosts.

Table 12.6: (continued)

Types of Communication	Representative Organisms	Description
"Dance Language" – a system of abstract symbolic communication	Honey bees	Thought that various species of honey bees are only invertebrates to have evolved this type of communication; angle at which bee dances represents direction relative to sun, length of dance represents distance to be flown.

Figure 12.32: A yellow-collared scape moth, showing the feathery antennae. (37)

Social insects, such as the termites (**Figure** 12.33), ants, and many bees and wasps (**Figure** 12.34), are the most familiar social species. They live together in large well-organized colonies. Only those insects which live in nests or colonies show any true capacity for homing. This allows an insect to return to a single hole among a mass of thousands of apparently identical holes, after a trip of up to several kilometers and as long as a year after last seeing

the area, as when an insect hibernates. A few insects migrate, but this is a larger-scale form of navigation and involves only a large general region, such as the overwintering of the monarch butterfly (**Figure** 12.35).

Figure 12.33: Damage to this nest, brings the workers and soldiers of this social insect, the termite, to repair it. (5)

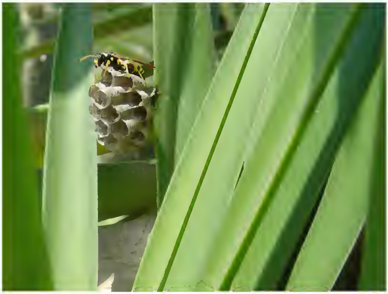

Figure 12.34: A wasp building its nest. (30)

Figure 12.35: Monarch butterflies in an overwintering cluster. (11)

Insects are divided into two major groups, the wingless and the winged insects. The wingless consists of two orders: the bristle tails and the silverfish. The winged orders of insects include the mayflies; dragonflies and damselflies; stoneflies; webspinners; angel insects; earwigs; grasshoppers, crickets, and katydids; stick insects; ice-crawlers and gladiators; cockroaches and termites; mantids; lice; thrips; true bugs, aphids, and cicadas; wasps, bees, and ants; beetles; twisted-winged parasites; snakeflies; alderflies and dobsonflies; lacewings and antlions; Scorpios and hangingflies (including fleas); true flies; caddisflies; and butterflies, moths, and skippers.

How Insects Obtain Food

Insects have a wide variety of appendages adapted for capturing and feeding on prey. In addition, as already discussed, they have sensory capabilities, which help them detect prey.

Insects have a wide range of mouthparts used for feeding. Specialized parts are mostly for piercing and sucking, as in mosquitoes and aphids. A number of insect orders have mouthparts that pierce food items to enable sucking of internal fluids. Some are herbivorous, like aphids and leafhoppers, while others are insectivorous, like assassin bugs and mosquitoes (females only).

Examples of chewing insects include dragonflies, grasshoppers, and beetles. Some larvae have chewing mouthparts, as in moths and butterflies.

Some insects use siphoning, as if sucking through a straw, as in moths and butterflies, where some of the mouthparts are adapted into an elongated sucking tube. You have probably seen a butterfly or moth poised at a flower while it siphons the nectar of the flower. Some moths, however, have no mouthparts at all.

Some insects are capable of sponging, as in the housefly. One of the mouthparts is specialized for this function, where liquid food is channeled to the esophagus. The housefly is able to eat solid food by secreting saliva and dabbing it over the food item. As the saliva dissolves the food, the sponging mouthpart absorbs the liquid food.

Reproduction and Life Cycle of Insects

Most insects have a high reproductive rate and can rapidly reproduce within a short period of time. With a short generation time, they evolve faster and can adjust to environmental changes faster. Although there are many forms of reproductive organs in insects, there is a basic design and function for each reproductive part. These parts may vary in shape (gonads), position, and number (glands), with different insect groups.

Most insects reproduce via sexual reproduction. The female produces eggs, which are fertilized by the male, and then the eggs are usually deposited in a precise microhabitat at or near the required food. Most insects are **oviviparous**, where the young hatch after the eggs have been laid. In some insects, there is asexual reproduction and in the most common type, the offspring are essentially identical to the mother. This is most often seen in aphids and scale insects.

An insect can have one of three types of metamorphosis and life cycle:

Table 12.7:

Type of Metamorphosis	None	Incomplete	Complete
Characteristics	Only difference between adult and larvae is size	Young, called **nymphs** (**Figure** 12.36), usually similar to adult, wings then appear as buds on nymphs or early forms; when last molt is completed wings expand to full adult size	Insects have different forms in immature and adult stages, have different behaviors, and live in different habitats; immature form is called larvae and remains similar in form but increases in size; they usually have chewing mouthparts even if adult mouthparts are sucking ones; at last larval stage of development insect forms into pupa (**Figure** 12.37), doesn't feed and is inactive; here wing development is initiated, and adult emerges
Example	Silverfish	Dragonflies	Butterflies and Moths

Importance of Insects

Many insects are considered to be pests by humans. In spite of this, insects are also very important. In the environment, some insects pollinate flowering plants, as in wasps, bees, butterflies, and ants. Many insects, especially beetles, are scavengers, feeding on dead animals and fallen trees, and insects are responsible for much of the process by which topsoil is created.

Insects also produce useful substances as honey, wax, lacquer, and silk. Honeybees have been cultured by humans for thousands of years for honey. The silkworm has greatly affected

Figure 12.36: Heteroptera nymphs and egg cases. (15)

Figure 12.37: The chrysalis (pupal stage) of a monarch butterfly. (19)

human history, as silk-driven trade established relationships between China and the rest of the world.

Fly larvae (maggots) were formerly used to treat wounds to prevent or stop gangrene, as they would only consume dead flesh. This treatment is finding modern usage in some hospitals. Adult insects such as crickets, and insect larvae of various kinds, are also commonly used as fishing bait.

In some parts of the world, insects are used for human food, while being a taboo in other places. Some people support this idea to provide a source of protein in human nutrition. Insects also have a role in controlling insect pests, as we will see in the next section.

Controlling Insect Pests

Insects commonly regarded as pests include those that are parasitic (mosquitoes, lice, bed bugs), transmit diseases (mosquitoes, flies), damage structures (termites), or destroy agricultural products (locusts, weevils). Many entomologists are involved in various forms of pest control, often using insecticides, but more and more relying on methods of biocontrol.

Biological control of pests in agriculture is a method of controlling pests that relies on predation, parasitism, herbivory, or other natural mechanisms. Insect predators, such as lady beetles and lacewings, are mainly free-living species that consume a large number of prey during their lifetime.

Parasitoids are species whose immature stage develops on or within a single insect host, ultimately killing the host. Most have a very narrow host range. Many species of wasps and some flies are parasitoids. Both of these types of predators and parasitoids are used to control insect pests. Pathogens are disease-causing organisms including bacteria, fungi, and viruses, which kill or debilitate their host and are specific to certain insect groups.

Most of the insecticides now applied are long-lasting synthetic compounds that affect the nervous system of insects on contact. Agricultural pesticides prevent a monetary loss of about $9 billion each year in the U.S. These benefits, however, must be weighed against the costs to society of using pesticides, which include human poisonings, fish kills, honeybee poisonings, and the contamination of livestock products.

Lesson Summary

- Insects are the most diverse group of animals on Earth; they are found in nearly all environments. They have segmented bodies with an exoskeleton; the nervous, respiratory, and circulatory systems are fairly simple. Insects are the only invertebrates to have developed flight. Insects have very sensitive and/or specialized organs of perception, including visual, chemical, heat-sensitive, and auditory. Some insects, like termites, ants, and many bees and wasps, are social and live together in large well-organized

colonies.

- Insect locomotion includes flight, walking, and swimming. There are two major groups of insects, the wingless and the winged, and these are further subdivided into various orders. Insects obtain food with the use of specialized appendages for capturing and eating the prey. Most insects have a high reproductive rate and can rapidly reproduce within a short period of time. An insect can have one of three types of metamorphosis and life cycle. Insects are beneficial both environmentally and economically. Insect pests can be controlled with chemical or with natural means, some of which are insects themselves; even though agricultural pesticides prevent a major monetary loss, they have major drawbacks, too.

Review Questions

1. What are the main characteristics of insects?
2. Why is the insect's circulatory system greatly reduced?
3. Give an example of mimicry in insects.
4. How do female accessory glands aid in the development of eggs?
5. What makes parasitoids especially effective against pests?

Further Reading / Supplemental Links

- http://homeschooling.gomilpitas.com/explore/bugs.htm
- http://rusinsects.com/links/view.php?id=20
- http://www.kidsolr.com/science/page18.html
- http://pestworldforkids.org/learninggames.html

Vocabulary

cuticle The outer layer of the exoskeleton.

exocuticle The thin and waxy water resistant outer layer of the cuticle.

nymphs A developmental stage of insects, where the young is usually similar to the adult.

oviviparous A method of reproduction where the young hatch after the eggs have been laid.

parasitoids Species whose immature stages develop on or within a single insect host, ultimately killing the host.

pheromones Chemicals secreted by animals, especially insects, that influence the behavior or development of others within the same species.

spiracles Openings on the sides of the insect abdomen, through which air is taken in.

Points to Consider

- Some of the adaptations that insects have evolved for a terrestrial existence are also displayed in amphibians and reptiles. What could be some of these? How are they similar and different?
- Insects have some very specialized sensory capabilities. How do you think these compare to those found in fish, amphibians, and reptiles?

Image Sources

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(2) Pearson Scott Foresman. http://commons.wikimedia.org/wiki/File:Thorax_(PSF).png. Public Domain.

(3) Jan Derk. *A Caribbean reef squid, an example of a cephalopod.*. Public Domain.

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(7) *A species of spider in its web.*. GNU-FDL.

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(22) Steven Johnson. http://commons.wikimedia.org/wiki/Image:Blue-lobster.jpg. GNU-FDL.

(23) Engeser. *Caterpillars feeding on a host plant.*. GNU-FDL.

(24) Daniel Ullrich. *A daddy-long-legs with a captured woodlouse.*. GNU-FDL.

(25) Chris Gladis. *close.jpg Giant spider crabs.*. CC-BY 2.0.

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(27) *A crayfish.*. GNU-FDL.

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(29) http://commons.wikimedia.org/wiki/Image:Ctenomorpha_chronus.jpg. GNU-FDL.

(30) Florian Siebeck. *A wasp building its nest.*. CC-BY-SA 2.0 Germany.

(31) Mila Zinkova. *A chiton and sea anemones at a tide pool.*. GNU-FDL.

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Chapter 13

Fishes, Amphibians, and Reptiles

13.1 Lesson 13.1: Introduction to Vertebrates

Lesson Objectives

- Describe the general features of chordates.
- List the three groups of chordates with their characteristics.
- List the general features of vertebrates.
- Describe the classification of vertebrates.

Check Your Understanding

- What is the function of the notochord in lower vertebrates?
- What happens to the notochord in higher vertebrates?

Introduction

It is hard to believe that some of the organisms that are chordates are closely related to us and vertebrates like us - everything from fish to amphibians and reptiles, to birds and mammals. **Chordates** are a group of animals that includes the vertebrates, as well as several closely related invertebrates. Some chordates, as we will soon see, appear to be nothing more than animals resembling marine invertebrates, like the tunicates in **Figure** 13.1. Chordates also include the lancelets, which appear as mostly featureless and simplified swimming animals (**Figure** 13.2). What these all have in common, though, are certain characteristics appearing either in the larval or adult forms, and which we will explore further in the first section.

Vertebrates all have backbones or spinal columns as well as some other defining character-

istics. About 58,000 species have been described and contain many familiar groups of large land animals.

Chordates

Chordates (phylum **Chordata**), including the vertebrates and several closely related invertebrates, are united by having, at some time in their life cycle, a **notochord,** a hollow dorsal nerve cord); pharyngeal slits (vertical slits in the pharynx wall, which help to filter out food particles); an **endostyle** (ciliated groove or grooves located in the pharynx), and a post-anal tail. The phylum is broken down into three subphyla: Urochordata (represented by tunicates), Cephalochordata (represented by lancelets) and Vertebrata (the vertebrates).

Urochordates have a notochord and nerve cord only during the larval stage and **cephalochordates** have a notochord and nerve cord but no vertebrae (bones in the backbone). In all vertebrates, except for hagfish, the notochord is generally reduced and the dorsal hollow nerve cord is surrounded with cartilaginous (made of cartilage, not bone) or bony vertebrae.

The urochordates consist of 3,000 species of tunicates (sessile (permanently attached) marine animals, with saclike bodies having thick membranes and siphons for water movement) and the cephalochordates consist of 30 species of lancelets (burrowing marine animals). The vertebrates encompass 57,739 species, including jawless and jawed vertebrates.

The origin of chordates is currently unknown. The first clearly identifiable chordates appear in the Cambrian Period (about 542 - 488 million years ago) as lancelet-like specimens.

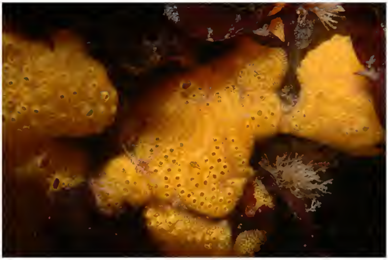

Figure 13.1: Tunicate colonies of *Botrylloides violaceus* (subphylum urochordata), showing oral tentacles at openings of oral siphons, which take in food and water, and expel waste and water. (14)

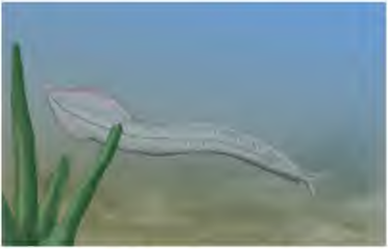

Figure 13.2: *Pikaia gracilens* (subphylum cephalochordates), perhaps the oldest known ancestor of modern vertebrates, resembled a living chordate, known as a lancelet, and perhaps swam much like an eel. *Pikaia* is thought to have had a very primitive, proto-notochord. Its "tentacles" may be related to those in present-day hagfish, a jawless chordate. (29)

What are Vertebrates?

Vertebrates, belonging to the subphylum **Vertebrata**, are chordates with a backbone or spinal column. Other characteristics are a braincase, or **cranium**, and an internal skeleton (the latter feature is present in all vertebrates except for lampreys). All vertebrates are most easily distinguished from all other chordates by having a defined head with pronounced cephalization. **Cephalization** is the concentration of nervous tissue towards one end of the organism. Vertebrates have sensory organs, especially eyes, concentrated at the front (anterior) end of the body. How do you think this type of body design is an advantage?

Typical vertebrate traits include:

- a backbone or spinal column
- braincase
- internal skeleton
- defined head with pronounced cephalization
- sensory organs, especially eyes

The vertebrate muscular system mostly consists of paired masses, as well as a central nervous system, partly located inside the backbone, when a backbone is present. Extant (living) vertebrates range in size from a carp species (**Figure** 13.3), at as little as 7.9 mm (0.3 in), to the blue whale, as large as 110 ft (**Figure** 13.4).

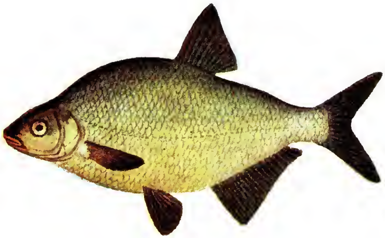

Figure 13.3: A species of carp, carp bream (*Abramis brama*). (10)

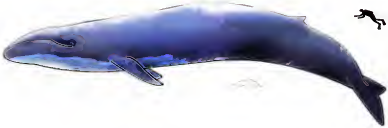

Figure 13.4: An image of the blue whale, the largest living vertebrate, reaching up to 33 m (110 ft) long. Shown below it is the smallest whale species, Hector's dolphin (about 1.4 m (5 ft) in length), and beside it, a human. (24)

Classification of Vertebrates

Vertebrates consist of both jawless and jawed vertebrates. The jawless vertebrates consist of more than 100 species including 65 species of hagfish, the conodonts, and the lampreys. The jawed vertebrates include over 900 species of cartilaginous fish, over 30,000 species of bony fish and over 18,000 species of tetrapods, or four-legged (or leg-like) vertebrates.

The bony fish are further divided into ray-finned and lobe-finned fish. The tetrapods consist of amphibians, reptiles, birds, mammal-like reptiles, and mammals.

Table 13.1: **Species of the Main Groups of Tetrapods**

Type of Tetrapod	Number of Species
Amphibians	6,000
Reptiles	8,225
Birds	10,000
Mammal-like Reptiles	4,500
Mammals	5,800

Lesson Summary

- Chordates are characterized by a notochord, pharyngeal slits, an endostyle, and a post-anal tail.
- There are three main groups of chordates, including tunicates, lancelets and vertebrates.
- Vertebrates are distinguished by having a backbone or spinal column.
- Vertebrates are classified into two major groups: those without jaws and those with jaws.

Review Questions

1. What features characterize the chordates?
2. What are the main features of vertebrates?
3. The first clearly-identifiable chordates are lancelet-like (small, burrowing marine animals with a lancet shape) specimens. List three ways in which these first chordates could have evolved into a swimming-like animal.
4. Which two structures that all chordates possess sometime during their life cycle are used for food gathering, and how are these structures used?
5. Why, do you think, cephalization is not necessary in urochordates and cephalochordates? Explain how this is illustrated in tunicates.

Further Reading / Supplemental Links

- http://www.ucmp.berkeley.edu/chordata/Chordata.html
- http://www.ucmp.berkeley.edu/vertebrates/vertintro.html
- http://en.wikipedia.org/wiki

Vocabulary

cephalization The placement of important sensory organs near or in the head.

cephalochordates A group of chordates with a notochord and nerve cord but no vertebrae.

chordata The phylum of chordates, containing the vertebrates and several closely related invertebrates.

cranium The braincase or skull.

endostyle A groove or pair of grooves having cilia; located in the pharynx; functions are to gather food particles and transport them along the digestive tract.

notochord A hollow dorsal nerve cord.

urochordates A group of chordates having a notochord and nerve cord present only during the larval stage.

vertebrata The subphylum of vertebrates, distinguished by having backbones or spinal columns.

Points to Consider

- The notochord's stiffness in many chordates may have evolved to facilitate the effectiveness of swimming in S-shaped movements. Think about the advantages this may have for water-living vertebrates.
- Unlike chordates with cephalization, cephalochordates (lancelets)have a mouth, but not a well-developed head, and have light-sensitive areas along their entire back, instead of at the anterior end of the body.
- How do you think cephalization could be an advantage in movement and feeding in fish?

13.2 Lesson 13.2: Fishes

Lesson Objectives

- List the general traits of fish.
- Describe the features of jawless fish.
- List the general features of the cartilaginous fish.
- Describe the features of bony fish and the significance of this superclass.
- List some of the reasons why fish are important.

Check Your Understanding

- What are the unique characteristics of vertebrates?
- What are the two main groups of vertebrates?

Introduction

So what exactly is a fish? You probably think the answer is obvious. You may say that a fish is an animal that swims in the ocean or a lake. But there is lots more to fish than that. Fish are aquatic vertebrates, which through evolution became a dominant form of sea life and eventually branched to create land vertebrates. They have a number of characteristic traits and are classified into two major groups: jawless and jawed fish. Jawed fish are further divided into those with bones and those with just cartilage. Fish, in general, are important in many ways to humans - economically, recreationally and culturally. Perhaps you can think of some of these ways?

Characteristics of Fish

Fish are vertebrates that are typically ectothermic, are covered with scales, have jaws and have two sets of paired fins and several unpaired fins. A typical fish has a streamlined body that allows it to swim rapidly, extracts oxygen from the water using gills or an accessory breathing organ to enable it to breathe atmospheric oxygen, and lays eggs that are fertilized internally or externally (**Figure** 13.5). Fish range in size from the 16 m (51 ft) whale shark to the 8 mm (just over ¼ of an inch) stout infantfish.

Traits of a typical fish include:

- Vertebrate
- Ectothermic
- Scales

- Jaws
- Two sets of paired fins
- Several unpaired fins
- Streamlined body
- Gills or an accessory breathing organ
- Lays eggs that are fertilized internally or externally

Figure 13.5: The humphead or Napoleon wrasse (*Cheilinus undulates*), showing some of the general traits of fish, including scales, fins and a streamlined body. (23)

There are exceptions to many of these traits. For example, tuna, swordfish, and some species of sharks show some warm-blooded adaptations, and are able to raise their body temperature significantly above that of the water around them. Some species of fish have a slower, but more maneuverable, swimming style, like eels and rays (**Figure** 13.6). Body shape and the arrangement of fins are highly variable, and the surface of the skin may be naked, as in moray eels, or covered with scales. Scales can be of a variety of different types.

Although most fish live in aquatic habitats, such as the ocean, lakes, and rivers, there are some that spend considerable time out of water. Mudskippers, for example, feed and interact with each other on mudflats for up to several days at a time and only go underwater when occupying burrows (**Figure** 13.7). They breathe by absorbing oxygen across the skin, similar to what frogs do.

Agnatha: Jawless Fishes

Agnatha is a superclass of jawless fish belonging to the phylum Chordata, subphylum Vertebrata (agnath means *jawless*). There are two extant (living) groups of jawless fish, the lampreys and the hagfish, with about 100 species in total. Although hagfish belong to the subphylum Vertebrata, they do not technically have vertebrae.

Figure 13.6: One of the cartilaginous fish, a stingray, showing very flexible pectoral fins connected to the head. (21)

Figure 13.7: A mudskipper, shown on the mudflats, where it spends time feeding and interacting with other individuals. (4)

In addition to the absence of jaws, Agnatha are characterized by absence of paired fins, the presence of a notochord both in larvae and adults, and seven or more paired gill pouches. The branchial arches (a series of arches that support the gills of aquatic amphibians and fishes) lie close to the body surface.

Agnatha have a light sensitive pineal eye (an eye-like structure that develops in some cold-blooded vertebrates) and do not have an identifiable stomach. They reproduce using external fertilization. They are ectothermic, have a cartilaginous skeleton, and a heart with two chambers.

Many agnathans from the fossil record were armored with heavy bony-spiky plates. The first armored agnathans - the Ostracoderms – were precursors to the bony fish and hence to the tetrapods, including humans.

What advantages would the advent of jaws have for fish? Such an adaptation would allow fish to eat a much wider variety of food, including plants and other organisms. In the next two sections you will be introduced to two groups of fish with jaws: those with a cartilaginous skeleton and those with a bony skeleton.

Cartilaginous Fishes

The cartilaginous fishes, or **Chondrichthyes**, are jawed fish with paired fins, paired nostrils, scales, two-chambered hearts, and skeletons made of cartilage rather than bone. The approximate 1,000 species are subdivided into two subclasses: Elasmobranchii (sharks, rays and skates) and Holocephali (chimaera, sometimes called ghost sharks). Fish from this group range in size from the dwarf lanternshark, at 16 cm (6.3 in), to the whale shark, up to sizes of 13.6 m (45 ft) (**Figure** 13.8).

Figure 13.8: One of two male whale sharks at the Georgia Aquarium. Whale sharks are the largest cartilaginous fish. (5)

Animals from this group generally have ratio of brain weight to body size that is close to that of mammals, and about ten times that of bony fishes. One of the explanations for their relatively large brains is that the density of nerve cells is much lower than in the brains of bony fishes, making the brain less energy demanding and allowing it to be bigger.

Since they do not have bone marrow (as they have no bones), red blood cells are produced in the spleen, in special tissue around the gonads, and in an organ called Leydig's Organ, only found in cartilaginous fishes. The tough skin of this group is covered with dermal teeth, or **placoid** scales, although they are mostly lost in adult Holocephali, making it feel like sandpaper. It is assumed that their oral teeth evolved from these dermal teeth, which migrated into the mouth.

The sharks, rays and skates are further broken into two superorders, one containing the rays

and skates, and the other containing the sharks (**Figure** 13.9). There are eight orders of sharks within the superorder. They are distinguished by such features as:

- Number of gill slits
- Numbers and types of fins
- Type of teeth
- Body shape
- The sawsharks, with an elongate, toothed snout used for slashing the fish that they eat.
- The bullhead sharks, with teeth used for grasping and crushing shellfish.
- Carpet sharks with **barbels**
- Nocturnal habits
- The groundsharks, with an elongated snout.
- The mackerel sharks, with large jaws and ovoviviparous reproduction, where the eggs develop inside the mother's body after internal fertilization, and the young are born alive.

Figure 13.9: A spotted Wobbegong shark (*Orectolobus maculatus*), at Shelly Beach, Sydney, Australia, showing skin flaps around the mouth and cryptic coloration. (1)

Bony Fishes

The **Osteichthyes,** or bony fish, contain almost 27,000 species, which are divided into two classes: the ray-finned fish (Actinopterygii) and the lobe finned fish (Sarcopterygii). Most

Figure 13.10: One of the only eight living species of lobe finned fish, the lungfish. (30)

Figure 13.11: One of the eight living species of lobe finned fish, the coelacanth. (26)

bony-fish belong to the Actinopterygii; there are only eight living species of lobe finned fish, including the lungfish (**Figure** 13.10) and coelacanths (**Figure** 13.11).

The vast majority of fish are osteichthyes, and this group is the most various of vertebrates, making them the largest group of vertebrates in existence today. They are characterized by a relatively stable pattern of cranial bones, and the head and pectoral girdles (arches supporting the forelimbs) are covered with large dermal bones (bones derived from the skin). They have a lung or swim bladder, which helps the body create a neutral balance between sinking and floating, by either filling up with or emitting such gases as oxygen; have bone fin rays (jointed, segmented rods) supporting the fins; have an operculum (a cover over the gill), which helps them to breathe without having to swim; and are able to see in color, unlike most other fish.

One of the best-known innovations of this group is the ability to produce endochondral or "replacement" bone, by replacing cartilage from within, with bone. This is in addition to the production of perichondral or "spongy bone." The effect is to create a relatively lightweight, flexible, "spongy" bone interior, surrounded by an outline of dense bone. This is still much heavier and less flexible than cartilage.

The ocean sunfish is the most massive bony fish in the world, up to 3.33 m (11 ft) in length and weighing up to 2,300 kg (5,070 lb) (**Figure** 13.12). Other very large bony fish include the Atlantic blue marlin, the black marlin, some sturgeon species, the giant grouper and the goliath grouper. In contrast, the dwarf pygmy goby measures only 1.5 cm (0.6 in).

Figure 13.12: An ocean sunfish, the most massive bony fish in the world, up to 11 ft in length and 5,070 lb in weight! (16)

Why Fish are Important

Now that you have some understanding of the general features of fish, you might come up with some ways in how fish are important. Of course, what comes to mind right away is their use for food (**Figure** 13.13). In fact, people from around the world either fish them from the wild or farm them in much the same way as cattle or chickens (**aquaculture**). Fish are also exploited for recreation, through angling and fishkeeping, and are commonly exhibited in public aquaria.

Figure 13.13: Workers harvest catfish from the Delta Pride Catfish farms in Mississippi. (25)

Fish also have an important role in many cultures and art through the ages, ranging as widely as deities and religious symbols to subjects of books and popular movies(**Figure** 13.14). For example, such deities that take the form of a fish are Ikee-Roa of the Polynesians, Dagon of various ancient Semitic peoples, and Matsya of the Dravidas of India. Fish have been used figuratively in many different ways, for example the ichthys used by early Christians to identify themselves and the fish as a symbol of fertility among Bengalis.

In literature, legends of half-human, half-fish mermaids are featured in stories of Hans Christian Anderson and fish feature prominently in *The Old Man and the Sea*. Fish and other fanciful fish also play a major role in such movies as *Splash, Jaws, Shark Tale,* and *Finding Nemo*.

Figure 13.14: Fish play an important role in many cultures, including art, through the ages. Here is a still life of fish, eels, and fishing nets, by Johannes Fabritius. (17)

Lesson Summary

- The general traits of fish help adapt them for living in an aquatic environment, mostly for swimming, and also for extracting oxygen.
- Fish are typically ectothermic, although some show warm-blooded adaptations.
- Jawless fish, the Agnatha, also have some other common features.
- Fish with jaws comprise both the cartilaginous fish and the bony fish.
- The cartilaginous fishes, or Chondrichthyes, include the sharks, rays, skates and chimaera.
- The bony fish, or Osteichthyes, is the largest group of vertebrates in existence today and have certain traits in common.
- Fish are important economically, recreationally and culturally.

Review Questions

1. What are the general traits of fish?
2. What are some exceptions to the general traits of fish?
3. Mudskippers are an example of a fish species that must absorb oxygen across the skin, instead of via gills, since they spend much of their time out of water. Describe an environmental situation in which air breathing would be of great use to a fish species.
4. What are the characteristics of jawless fish?
5. What is one structure only found in cartilaginous fishes and what is its function?
6. What are some reasons why it would be an advantage for fish to be endothermic?

7. List some ways that fish are important.

Further Reading / Supplemental Links

- Unabridged Dictionary, Second Edition. Random House, New York, 1998.
- http://kids.nationalgeographic.com/Animals
- http://www.fws.gov/educators/students.html
- http://www.igfa.org/kidshome.asp
- http://www.pbs.org/emptyoceans/educators/activities/fish-youre-eating.html
- http://en.wikipedia.org

Vocabulary

agnatha A superclass of jawless fish, belonging to the phylum Chordata, subphylum Vertebrata.

aquaculture The raising of aquatic plants and animals, especially seaweed, shellfish and other fish, in environments either natural or with controlled freshwater or marine conditions.

barbels A thin structure on the external part of the head, such as the jaw, mouth or nostrils, of certain fishes.

chondrichthyes The group of cartilaginous fishes, containing sharks, rays, skates and chimaeras.

ectothermic Cold-blooded

osteichthyes Contains all the bony fish, divided into the ray-finned and lobe finned fish.

ovoviviparous reproduction The eggs develop inside the mother's body after internal fertilization, and depend on the yolk for most of the nutrition; the young are born alive.

placoid Plate-like, as in the scales of sharks.

Points to Consider

- Juvenile bichirs, a type of fish, have external gills, a very primitive feature that they hold in common with larval amphibians. Think about how the external gills could be a transition between internal gills and lungs?
- Lungfish and bichirs have paired lungs similar to those of tetrapods and must rise to the water's surface to gulp fresh air through the mouth and pass spent air out though the gills. Discuss how lungfish could be similar to and different from tetrapods in the way they breathe?
- The structure, the pineal body, located in the brain, performs many different functions including detecting light, maintaining circadian rhythms and controlling color changes. What structures could perform similar functions in amphibians, as a result of living on land?

13.3 Lesson 13.3: Amphibians

Lesson Objectives

- Describe amphibian traits.
- List the features of salamanders.
- Compare and contrast frogs and toads with other amphibians.
- Describe the roles of amphibians.

Check Your Understanding

- What are some adaptations that amphibians, like fish, have for living in the water?
- What are the characteristics that amphibians share with all other vertebrates?

Introduction

What group of animals begins its life in the water, but then spends most of its life on land? You were right, if you guessed amphibians. Amphibians are a group of vertebrates that has adaptations for both aquatic and terrestrial lifestyles. Evolutionarily, their ancestors made the transition from the sea to land. They comprise approximately 6,000 species of various body types, physiology, and habitats, ranging from tropical to subarctic regions.

Characteristics of Amphibian

Amphibians are ectothermic vertebrates, belonging to the class Amphibia and consist of three orders: Urodela, containing the salamanders and newts; Manure, consisting of frogs and toads; and Apoda, containing the caecilians. The larvae are typically aquatic and breathe using gills. The adults are typically semiterrestrial and breathe both through moist skin and by lungs.

For the purposes of reproduction, most amphibians are bound to fresh water. Although there are no true seawater amphibians, a few tolerate brackish (slightly salty) water. Some species do not need any water whatsoever, and several species have also adapted to arid and semi-arid environments, but most still need water to lay their eggs.

In general, the life cycle of amphibians begins with a shell-less egg stage, usually laid the previous winter in a pond. A larval stage follows in which the organism is legless, fully aquatic and breathes with exterior gills. After hatching, the larvae start to transform gradually (metamorphosis) into the adult's appearance, including loss of gills, growth of four legs, and the ability to live in a terrestrial environment.

Adaptations for living in a terrestrial environment include replacement of gills with another respiratory organ, such as lungs; a development of glandular (containing cells, a group of cells, or an organ producing a secretion) skin to avoid dehydration, and the development of eyelids and adaptation to vision outside the water. An eardrum also develops that separates the external ear from the middle ear and, in frogs and toads, the tail disappears.

Salamanders

This is a group of approximately 500 species of amphibians, typically characterized by slender bodies, short legs, and long tails, and most closely related to the caecilians, little known legless amphibians (**Figure** 13.16). Having moist skin, salamanders (**Figure** 13.15) rely on habitats in or near water or under some protection on moist ground, often in a swamp. Some species are aquatic throughout life, some are aquatic intermittently and some are entirely terrestrial as adults.

Respiration varies among the different species of salamanders; in those that retain lungs, respiration occurs through the gills as water passes over the gill slits. Some terrestrial species have lungs that are used in respiration in a similar way as in mammals. Other terrestrial salamanders lack both lungs and gills and exchange gases through their skin. This is known as **valarian respiration,** in which the capillary beds are spread throughout the epidermis.

Hunting prey is another unique aspect of salamanders. Muscles surrounding the **hyoid bone** contract to create pressure and "shoot" the hyoid bone out of the mouth along with the tongue. The tip of the tongue has mucus which creates a sticky end to which the prey is attached and captured. Muscles in the pelvic region are then used to bring the tongue and hyoid back to their original positions. Another trait, unique among vertebrates, is the

Figure 13.15: The marbled salamander, *Ambystoma opacum*, shows the typical salamander body plan: slender body, short legs, long tail and moist skin. (27)

Figure 13.16: A species of African caecilian, *Boulengerula taitanus*, a legless amphibian, most closely related to the salamanders. (13)

ability to regenerate lost limbs, as well as other body parts, in a process known as **ecdysis.**

Salamanders are found in most moist or arid habitats in the northern hemisphere. They are generally small, but some can reach 30 cm (a foot) or more, as in the mudpuppy of North America. In Japan and China, the giant salamander reaches 1.8 m (6 ft) and weighs up to 30 kg (66 lb) (**Figure** 13.17).

Figure 13.17: The Pacific giant salamander can reach up to 6 ft in length and 66 lb in weight. (12)

The order Urodela, containing the salamanders and newts, is divided into three suborders. These consist of the giant salamanders (including the hellbender and Asiatic salamanders), advanced salamanders (including lungless salamanders, mudpuppies, and newts), and sirens.

Frogs and Toads

Frogs and toads (**Figure** 13.18) are amphibians in the order Anura. A distinction is often made between frogs and toads on the basis of their appearance, caused by the **convergent adaptation** among so-called toads to dry environments (leathery skin for better water retention and brown coloration for camouflage), but this distinction has no taxonomic basis. One family, *Bufonidae,* is exclusively given the common name "toad," but many species from other families are also called "toads."

Frogs are distributed from the tropics to subarctic regions, but most species are found in tropical rainforests. Consisting of more than 5,000 species (about 88% of amphibian species are frogs), they are among the most diverse groups of vertebrates. Frogs range in size from 10 mm (less than ½ in) in species in Brazil and Cuba to the 300 mm (1 ft) goliath frog of

Figure 13.18: A species of toad, showing typical characteristics of leathery and warty skin, and brown coloration. (9)

Cameroon.

Adult frogs are characterized by long hind legs, a short body, webbed digits, protruding eyes and no tail. They also have a three-chambered heart, which they share with all tetrapods except birds and mammals. Most frogs have a semi-aquatic lifestyle, but move easily on land by jumping or climbing. They typically lay their eggs in puddles, ponds or lakes, and their larvae, or tadpoles, have gills and develop in water.

The reliance of frogs on an aquatic environment for the egg and tadpole stages gives rise to a variety of mating behaviors that include the calls used by the males of most species to attract females to the bodies of water chosen for breeding. Frogs are most noticeable by these calls, which can occur during the day or night.

Frogs are usually well suited to jumping with long hind legs and elongated ankle bones. They have a short vertebral column, with no more than ten free vertebrae, followed by a fused tailbone. Skin hangs loosely on the body because of the lack of loose connective tissue(tissue that surrounds, supports, or connects organs, other tissues, etc.). Skin texture varies, either smooth, warty or folded.

Frogs have three eyelid membranes: one is transparent to protect the eyes underwater, and two vary from translucent to opaque. Frogs have a **tympanum,** involved in hearing, on each side of the head, and in some species, is covered by skin.

Adult frogs are carnivorous and eat mostly arthropods, annelids and gastropods. Adults have a ridge of very small cone teeth, called maxillary teeth, around the upper edge of the jaw and they have what are called vomerine teeth on the roof of the mouth. Since they don't have teeth on their lower jaw, frogs usually swallow their food whole, and use the teeth they do have to hold the prey in place. Toads do not have any teeth, and so they must swallow

their prey whole.

Roles of Amphibians

Frogs are raised commercially as a food source (frog legs are a delicacy in China, France, the Philippines, northern Greece and the American south, especially Louisiana). They are used in cloning research and other branches of embryology, because they lack egg shells, and therefore facilitate observations of early development. The African clawed frog or platanna (*Xenopus laevis*) is used as a **model organism** (a species that is extensively studied to understand certain biological phenomena) in developmental biology, because it is easy to raise in captivity and has a large and easily manipulated embryo. Many Xenopus genes have been identified, isolated, and cloned as a result.

Many environmental scientists believe that amphibians, including frogs, are excellent biological indicators of broader ecosystem health because of their intermediate position in food webs, their permeable skins, and typically biphasic life (aquatic larvae and terrestrial adults).

Amphibians also figure prominently in folklore, fairy tales and popular culture. Numerous legends have developed over the centuries around the salamander (its name originates from the Persian, for "fire" and "within) , many related to fire. This connection likely originates from the tendency of many salamanders to dwell inside rotting logs. When placed into the fire, salamanders would escape from the logs, lending to the belief that the salamander was created from flames.

Associations of the salamander with fire appear in the Talmud (a collection of Jewish law and tradition) and the Hadith (a traditional account of things said or done by Muhammad or his companions), as well as in the writings of Conrad Lycosthenes (a sixteenth century humanist and encyclopedist), Benvenuto Cellini (a sixteenth century Italian goldsmith, painter, sculptor, musician, and soldier), science fiction authors Ray Bradbury and David Weber, Paracelsus (a fifteenth century alchemist, physician, and astrologer) and Leonardo da Vinci.

In other representations in popular culture, salamanders are known as minor snake demons according to some folklore; they, and frogs, appear as some characters in video games; salamanders appear in anime series, and they were even the focus of a dance craze (the Salamander Homp) in the early 1980's. Frogs tend to be portrayed as benign, ugly, and clumsy, but with hidden talents. Examples include Michigan J. Frog, *The Frog Prince,* and Kermit the Frog.

The Moche people of ancient Peru worshiped animals and often depicted frogs and toads in their art. The toad also appears as symbol and in story in Vietnamese culture.

Lesson Summary

- Amphibians have adaptations for both aquatic, including gills, and terrestrial, including lungs and moist skin, lifestyles.
- Most amphibians are bound to water for reproduction.
- Development includes a shell-less egg, larval stage and adult.
- Salamanders have some unique features, including the use of the hyoid bone in hunting prey, and the process of ecdysis.
- Adult frogs and toads have features for living in the water (such as webbed digits) and for living on the land (such as long hind legs for jumping).
- Frogs are well known for their mating calls, which are used to attract females to aquatic breeding grounds.
- Amphibians play a role economically as a food source; are used in various types of biological research, can serve as indicators of ecosystem health, and figure prominently in folklore and popular culture.

Review Questions

1. Describe the general traits of amphibians.
2. Describe the life cycle of amphibians.
3. What are some adaptations of amphibians for living in a terrestrial environment?
4. A frog's skin must remain moist at all times in order for oxygen to pass through the skin and into the blood. Why does this fact make frogs susceptible to many toxins in the environment?
5. The permeability of a frog's skin can result in water loss. What adaptations would benefit a frog by counteracting this water loss?
6. Name how one feature of frog development lends itself to research applications.
7. Amphibians have a number of adaptations which make it easy for them to avoid predation. Describe some of these.

Further Reading / Supplemental Links

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- http://en.wikipedia.org/wiki
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- http://www.amphibianark.org/yearofthefrog.htm
- http://www.epa.gov/gmpo/education/photo/amphibians.html

Vocabulary

convergent adaptation The appearance of similar traits in groups of animals that are evolutionarily unrelated to each other.

ecdysis The ability to regenerate lost limbs, as well as other body parts.

hyoid bone A U-shaped bone at the root of the tongue; in salamanders it is used to help catch prey.

tympanum Equivalent to the middle ear; used in hearing.

valarian respiration Respiration in which the capillary beds are spread throughout the epidermis, so that gases can be exchanged through the skin.

Points to Consider

- Future studies of molecular genetics should soon provide further insights to the evolutionary relationships among frog families. These studies will also clarify relationships among families belonging to the rest of vertebrates as well.
- Toxins obtained from some frog species may have potential as therapeutic drugs. The alkaloid epibatidine, a painkiller 200 times more potent than morphine, is found in some species of poison dart frogs. Other chemicals isolated from frog skin may offer resistance to HIV infection. As we will see in the next lesson, reptiles also possess chemicals and unique genes that are useful for medical purposes.
- Although care of offspring is poorly understood in frogs, it is estimated that up to 20% of amphibian species care for their young, and that there is a great diversity of parental behaviors. As you begin to examine the reproductive system of reptiles in the next lesson, think about what kinds of parental behaviors reptiles might have and how they compare to that of amphibians.

13.4 Lesson 13.4: Reptiles

Lesson Objectives

- List reptile traits.
- Describe the general features of lizards and snakes.
- List the characteristics of alligators and crocodiles.
- Describe the traits of turtles.
- Explain the importance of reptiles.

Check Your Understanding

- What are some adaptations for living on land that are present in the amphibians?
- What features present in amphibians are also useful to reptiles for an aquatic lifestyle?

Introduction

While some types of reptiles, like snakes, alligators, and crocodiles, often have a bad reputation due to their venom, as in snakes, or their aggressive behavior, as in all three groups, reptiles are important both ecologically and economically, as we will see later in this lesson. They also possess some unique traits and interesting behaviors, which we will also explore in greater detail.

Reptiles are tetrapods and **amniotes,** whose embryos are surrounded by an amniotic membrane. Modern reptiles inhabit every continent with the exception of Antarctica, and are represented by four living orders: Squamata (lizards, snakes and amphisbaenids or "worm-lizards"), Crocodilia (crocodiles, gharials (**Figure** 13.19), caimans, and alligators) Testudines (turtles and tortoises) and Sphenodontia (tuatara) (**Figure** 13.20).

Figure 13.19: An Indian gharial crocodile. (3)

Traits of Reptiles

Reptiles are air-breathing, cold-blooded vertebrates that have skin covered in scales. The majority of species are **oviparous** (egg-laying) although certain species of squamates are capable of giving birth to live young. This is achieved, either by ovoviviparity (egg retention within the female until birth), or viviparity (offspring born without use of calcified eggs).

Figure 13.20: A tuatara. (19)

Many of the viviparous species feed their fetuses through various forms of placenta, similar to those of mammals, with some providing initial care for their hatchlings. The degree of viviparity varies: some species simply retain the eggs until just before hatching, others provide maternal nourishment to supplement the yolk, while still others lack any yolk and provide all nutrients via a placenta.

All reproductive activity occurs with the cloaca, the single exit/entrance at the base of the tail, where waste is also eliminated. Most reptiles lay amniotic eggs covered with leathery or calcareous shells. An amnion (the innermost of the embryonic membranes), chorion (the outermost of the membranes surrounding the embryo) and allantois (a vascular embryonic membrane) are present during embryonic life. There are no larval stages of development.

Most reptiles reproduce sexually, although six families of lizards and one snake are capable of asexual reproduction. In some species of squamates, a population of females is able to produce a nonsexual diploid clone of the mother. This asexual reproduction called **parthenogenesis** occurs in several species of gecko, and is particularly widespread in the teiids and lacertids.

Extant reptiles range in size from the newly-discovered Jaragua Sphaero, at 1.6 cm (0.6 in), to the saltwater crocodile, at up to 7 m (23 ft).

Most reptiles have a closed circulatory system with a three-chambered heart consisting of two atria and one ventricle. All reptiles breathe using lungs, although aquatic turtles have developed more permeable skin, and some species have modified their cloacas to increase the area for gas exchange. Excretion is performed mainly by two small kidneys.

The reptilian brain is similar to that of amphibians, except the cerebrum and cerebellum are slightly larger. Most typical sense organs are well developed with certain exceptions most notably the snakes lack of external ears (middle and inner ears are present). All reptilians have advanced visual depth perception compared to other animals.

Lizards and Snakes

Lizards and snakes belong to the largest recent order of reptiles (Squamata). Members of the order are distinguished by their skin, which bears horny scales or shields. They also possess movable quadrate bones, making it possible to move the upper jaw relative to the braincase. This is particularly visible in snakes, which are able to open their mouths very widely to accommodate comparatively large prey (**Figure** 13.21).

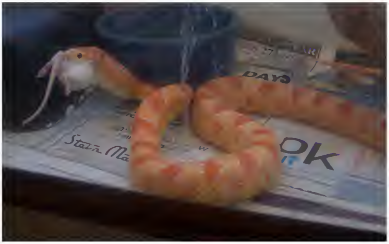

Figure 13.21: A corn snake swallowing a mouse. (20)

Lizards are a large and widespread group of reptiles, with nearly 5,000 species, ranging across all continents except Antarctica. Most lizards have four limbs, external ears, movable eyelids, a short neck, a long tail, and are insectivores. Many can shed their tails in order to escape from predators.

Vision, including color vision, is particularly well developed in lizards, and most communicate with body language, bright colors, or **pheromones.** Adults range from a few cm (1 in) in length (some Caribbean geckos) to nearly 3 m (10 ft) (**Figure** 13.22), although most species are less than 220 g (0.5 lb).

Encompassing 40 families, there is tremendous variety in color, appearance and size of lizards. Most lizards are oviparous, although a few species are viviparous. Many are also capable of regeneration of lost limbs or tails. Almost all lizards are carnivorous, although most are so small that insects are their primary prey. A few species are omnivorous or herbivorous,

Figure 13.22: A Komodo dragon, the largest of the lizards, attaining a length of 10 ft. (28)

and others have reached sizes where they can prey on other vertebrates, such as birds and mammals.

Many lizards are good climbers or fast sprinters. Some can run bipedally, such as the collared lizard, and some, like the basilisk, can even run across the surface of water to escape. Many lizards can change color in response to their environments or in times of stress (**Figure** 13.23). The most familiar example is the chameleon, but more subtle color changes occur in other lizard species, such as the anole, as well.

Some lizard species, including the glass lizard and flap-footed lizards, have lost their legs or reduced them to the point they are non-functional. However, some vestigial structures remain. While some legless lizards, like flap-footed lizards, are similar in appearance to snakes, they can be distinguished by such features as their external ears.

All snakes are carnivorous and can be distinguished from legless lizards by lack of eyelids, limbs, external ears, and vestiges of forelimbs. The 2,700+ species of snakes occur in every continent except Antarctica and range in size from the tiny, 10 cm (4 in) long thread snake to pythons and anacondas over 5 m (17 ft) long (**Figure** 13.24). In order to accommodate snakes' narrow bodies, paired organs (such as kidneys) appear one in front of the other instead of side by side.

While venomous snakes comprise a minority of the species, some possess potent venom capable of causing painful injury or death to humans. However, snake venom is primarily for killing and subduing prey rather than for self-defense. All snakes are strictly carnivorous, eating small animals including lizards, other snakes, small mammals, birds, eggs, fish, snails or insects.

Figure 13.23: A species of lizard, showing general body form and camouflage against background. (8)

Figure 13.24: A species of anaconda, one of the largest snakes, getting as long as 17 ft. (7)

Because snakes cannot bite or tear their food to pieces, prey must be swallowed whole. The body size of a snake has a major influence on its eating habits. The snake's jaw is one of the most unique jaws in the animal kingdom. Snakes have a very flexible lower jaw, the two halves of which are not rigidly attached, and numerous other joints in their skull, allowing them to open their mouths wide enough to swallow their prey whole.

Some snakes have a venomous bite, which they use to kill their prey before eating it; others kill their prey by constriction, and still others swallow their prey whole and alive. After eating, snakes become dormant while the process of digestion takes place. The process is highly efficient, with the snake's digestive enzymes dissolving and absorbing everything but the prey's hair and claws.

Most snakes use specialized belly scales to travel, gripping surfaces. The body scales may be smooth, keeled or granular (**Figure** 13.25). Snakes' eyelids are transparent "spectacle" scales which remain permanently closed. In the shedding of scales, or molting, the complete outer layer of skin is shed in one layer (**Figure** 13.26). Molting replaces old and worn skin, allows the snake to grow and helps it get rid of parasites such as mites and ticks.

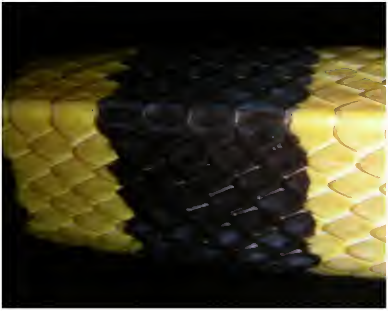

Figure 13.25: A close up of snake scales of a banded krait, *Bungarus fasciatus*, showing Black and yellow alternating bands and spaces between scales. (6)

Although a wide range of reproductive modes are used by snakes, all snakes employ internal fertilization, accomplished by means of paired, forked hemipenes, which are stored inverted in the male's tail. Most species of snakes lay eggs and most species abandon them shortly after laying.

Figure 13.26: A northern water snake shedding its skin. (2)

Alligators and Crocodiles

Crocodilia, containing both alligators and crocodiles, is an order of large reptiles. Reptiles belonging to Crocodilia are the closest living relatives of birds, as the two groups are the only known living descendants of the Archosauria, a subclass of reptiles, including the dinosaurs. The basic crocodilian body plan (**Figure** 13.27) is a very successful one that has changed little over time; modern species closely resemble their Cretaceous ancestors of 84 million years ago. Crocodilians have a flexible semi-erect (semi-sprawled) posture. They can walk in low, sprawled "belly walk," or hold their legs more directly underneath them to perform the "high walk." Most other reptiles can only walk in a sprawled position.

All crocodilians have, like humans, **thecodont dentition**, (teeth set in bony sockets), but unlike mammals, they replace their teeth throughout life. Crocodilians also have a secondary bony palate that enables them to breathe when partially submerged, even if the mouth is full of water. Their internal nostrils open in the back of their throat, where a special part of the tongue called the "palatal valve" closes off their respiratory system when they are underwater, allowing them to breathe when submerged.

Crocodiles and gharials (large crocodilians having elongated jaws) have modified salivary glands on their tongue (salt glands), which are used for excreting excess salt ions from their bodies. Crocodilians are often seen lying with their mouths open, a behavior called gaping. One of its functions is probably to cool them down, but it may also have a social function.

Like mammals and birds and unlike other reptiles, crocodiles have a four-chambered heart; however, unlike mammals, oxygenated and deoxygenated blood can be mixed. Crocodilians

Figure 13.27: Two Nile crocodiles, showing the basic crocodilian body plan. (11)

are known to swallow stones, known as gastroliths, which act as a ballast in addition to aiding post-digestion processing of their prey. The crocodilian stomach is divided into two chambers, the first is powerful and muscular, like a bird gizzard, where the gastroliths are found. The other stomach has the most acidic digestive system of any animal and can digest mostly everything from their prey: bones, feathers and horns.

The sex of developing crocodilians is determined by the incubation temperature of the eggs. This means crocodilians do not have genetic sex determination, but instead have a form of environmental sex determination, which is based on the temperature that embryos are subjected to early in their development.

Like all reptiles, crocodilians have a relatively small brain, but the crocodilian brain is more advanced than those of other reptiles. As in many other aquatic or amphibian tetrapods, the eyes, ears, and nostrils are all located on the same plane. They see well during the day and may even have color vision, plus the eyes have a vertical, cat-like pupil, which gives them excellent night vision. A third transparent eyelid, the **nictitating membrane,** protects their eyes underwater.

While birds and most reptiles have a ring of bones around each eye which supports the eyeball (the sclerotic ring), the crocodiles lack these bones, just like mammals and snakes. The eardrums are located behind the eyes and are covered by a movable flap of skin. This flap closes, along with the nostrils and eyes, when they dive, preventing water from entering their external head openings. The middle ear cavity has a complex of bony air-filled passages and a branching Eustachian tube. Eustachian tubes will be discussed in the chapter titled *Controlling the Body.*

The upper and lower jaws are covered with sensory pits, which encase bundles of nerve fibers that respond to the slightest disturbance in surface water. Thus they can detect vibrations and small pressure changes in water, making it possible for them to detect prey, danger and intruders even in total darkness.

Turtles

Turtles are reptiles of the order Testudines, most of whose body is shielded by a special bony or cartilaginous shell developed from their ribs. About 300 species are alive today and some are highly endangered. Turtles cannot breathe in water, but can hold their breath for various periods of time. Like other reptiles, turtles are **poikilothermic** (or "of varying temperature"). Like other amniotes, they breathe air and don't lay eggs underwater, although many species live in or around water.

The largest chelonian (all living species) is the great leatherback sea turtle (**Figure** 13.28), which reaches a shell length of 200 cm (7 ft) and can reach a weight of over 900 kg (2,000 lb). Freshwater turtles are generally smaller, but the largest species, the Asian softshell turtle, has been reported up to 200 cm (7 ft). The only surviving giant tortoises are on the Seychelles and Galapagos Islands and can grow to over 130 cm (4 ft) in length and weigh about 300 kg (670 lb) (**Figure** 13.29).

Figure 13.28: The largest living chelonian, the leatherback turtle, which can reach up to 7 ft in length and over 2,000 lb. (15)

The smallest turtle is the speckled padloper tortoise of South Africa, measuring no more than 8 cm (3 in) in length, and weighing about 140 g (5 oz). Turtles are broken down into two groups, according to how they evolved a solution to the problem of withdrawing their neck into the shell: the Cryptodira, which can draw their neck in while contracting it under their spine, and the Pleurodira, which contract their neck to the side.

Figure 13.29: A Galapagos giant tortoise, pictured here, can grow to over 4 ft in length and weigh about 670 lb. (18)

Most turtles that spend most of their life on land have their eyes looking down at objects in front of them. Some aquatic turtles, such as snapping turtles and soft-shelled turtles, have eyes closer to the top of the head. These species of turtles can hide from predators in shallow water where they lie entirely submerged except for their eyes and nostrils. Sea turtles (**Figure** 13.30) possess glands near their eyes that produce salty tears that rid their body of excess salt taken in from the water they drink.

Figure 13.30: A species of sea turtle, showing placement of eyes, shell shape, and flippers. (22)

Turtles are thought to have exceptional night vision due to the unusually large number of rod cells in their retinas. Turtles have color vision with a wealth of cone subtypes with

sensitivities ranging from the near ultraviolet to red. (For a description of rods and cones, see chapter titled *Controlling the Body*). Turtles have a rigid beak and use their jaws to cut and chew food. Instead of teeth, the upper and lower jaws of the turtle are covered by horny ridges. Carnivorous turtles usually have knife-sharp ridges for slicing through their prey. Herbivorous turtles have serrated-edged ridges that help them cut through tough plants.

Although many turtles spend large amounts of their lives underwater, all turtles and tortoises breathe air, and must surface at regular intervals to refill their lungs. They can also spend much of their lives on dry land. Turtles lay eggs, like other reptiles, and which are slightly soft and leathery. The eggs of the largest species are spherical, while the eggs of the rest are elongated. In some species, temperature determines whether an egg develops into a male or female. Large numbers of eggs are deposited in holes dug into mud or sand. They are then covered and left to incubate by themselves. When the turtles hatch, they squirm their way to the surface and head toward the water.

Importance of Reptiles

The chief impact of reptiles, such as lizards, on humans is positive as they are significant predators of pest species. Snakes are also very useful rat exterminators, for example, in the Irula villages of India.

Reptiles can be important as food sources: green iguanas are eaten in Central America, the tribals of "Irulas" from Andhra Pradesh and Tamil Nadu in India are known to eat some of the snakes they catch, Cantonese snake soup is consumed by local people in the fall to prevent colds, cooked rattlesnake meat is commonly consumed in parts of the Midwestern United States, and turtle soup is widely consumed.

Reptiles also make good pets. Numerous lizard species are prominent in the pet trade. In the Western world, some snakes, especially docile species such as the ball python and corn snake, are kept as pets. Turtles, particularly small terrestrial and freshwater turtles, are also commonly kept as pets. Among the most popular are the Russian tortoises, Greek spur-thighed tortoises and red-ear sliders (or terrapin).

For medical and scientific research, snake venom collected by the "Irulas" is used for producing life-saving antivenin and for other medicinal products. Observations about turtle longevity (the liver, lungs and kidneys of a centenarian turtle are virtually indistinguishable from those of its immature counterpart) have inspired genetic researchers to begin examining the turtle genome for longevity genes.

Finally, reptiles play a significant role in folklore, religion and popular culture. Lizard symbology plays important, though rarely predominant roles in some cultures (e.g. Tarrotarro in Australian mythology). The Moche people of ancient Peru worshipped animals and often depicted lizards in their art. Crocodilians have starred in several science fiction movies such as Lake Placid and DinoCroc. There are also many cultural depictions of turtles and

tortoises.

Snakes or serpents (the latter usually referring to a mythic or symbolic snake) are associated with healing in the Bible (the account of the brass serpent of Moses) as well as with the devil (the Biblical account of Adam and Eve). The periodic renewal, as in the shedding of snake skin, has led to the snake being a symbol of healing and medicine, as pictured in the Rod of Asclepius (**Figure** 13.31). In Egyptian history, the snake occupies a primary role with the Nile cobra adorning the crown of the pharaoh in ancient times. It was worshipped as one of the gods and was also used for sinister purposes, such as murder of the adversary and ritual suicide by the Egyptian queen Cleopatra. Snakes also play a role in Greek mythology, in Indian tradition and religion, and in other religions and customs.

Lesson Summary

- Reptiles are air-breathing, cold-blooded vertebrates characterized by a scaly skin.
- Reptiles have a variety of reproductive systems, with different strategies for providing nutrition to developing young.
- Lizards and snakes are distinguished by a unique type of scaly skin and movable quadrate bones.
- There is a tremendous variety in color, appearance and size of lizards, and they have some unique adaptations, including regeneration of lost limbs or tails and changing color.
- Snakes are distinguished by lack of eyelids, limbs, external ears and vestiges of fore-limbs.
- Snakes have various adaptations for killing and eating their prey.
- Crocodilia have a flexible semi-erect posture, thecodont dentition, replacement of teeth, and a secondary bony palate.
- The sex of developing crocodilians is determined by the incubation temperature of the eggs.
- Other crocodilian traits, such as salt glands, nictitating membranes, ear flaps and sensory pits, are adaptations for aquatic living.
- Turtles are characterized by a special bony or cartilaginous shell; have specialized adaptations for aquatic living, such as eye placement and salt glands, and adaptations for terrestrial living as well (placement of eyes and protection of eggs).
- Reptiles play important roles as predators of pest species, food sources, pets, in medical and scientific research, and in folklore, religion and popular culture.

Review Questions

1. Describe the general traits of reptiles.
2. Describe the different types of reproduction in reptiles.
3. How are snakes distinguished from legless lizards?

Figure 13.31: The Rod of Asclepius, where the snake is a symbol of healing and medicine. (31)

4. Pit vipers, pythons and some boas have infrared-sensitive receptors in deep grooves between the nostril and eye. What role might such receptors play?
5. Name two adaptations of a crocodilian stomach which help it in digestion.
6. The shape and structure of a turtle's shell can give its inhabitant advantages for avoiding predators, aid in swimming and diving, and for walking on land. Given what you know about a turtle's shell, explain how the structure and shape could help the turtle in the above situations.

Further Reading / Supplemental Links

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Vocabulary

amniotes Vertebrates whose embryos are surrounded by an amniotic membrane.

nictitating membrane A third transparent eyelid.

oviparous Reproduction involving the laying of eggs.

parthenogenesis A form of asexual reproduction, where the egg develops without fertilization.

pheromones Chemicals released by an animal that influence the behavior or physiology of other individuals of the same species.

poikilothermic Cold-blooded; without the ability to independently warm the blood.

the codont Where teeth are set in bony sockets.

Points to Consider

- Some lizards have a dewlap, a brightly colored patch of skin on the throat, which is used in displays. What colorful displays do you think are used for courtship in birds and mammals?
- Lizards and snakes use smell to track their prey, using the Jacobson's or vomeronasal organ in the mouth, as well as a forked tongue. How do you think this compares to the sense of smell in birds and mammals and the structures used for smelling in these groups?
- Like the scales comprising the shell of a turtle, or the cross-section of a tree trunk, crocodile osteoderms (small plates of bone under the scales) have annual growth rings, and by counting them it is possible to tell their age. Can we determine age in the same way in either birds or mammals?

Image Sources

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Chapter 14

Birds and Mammals

14.1 Lesson 14.1: Birds

Lesson Objectives

- List and describe general traits of birds.
- Explain how birds are adapted for flight.
- List different breeding systems in birds and describe nesting, incubation and parental care.
- Illustrate the diversity of birds with examples of some of the varied groups.
- Explain how birds are important, both economically and ecologically.

Check Your Understanding

- Birds and reptiles have some traits in common. For example, birds are egg-layers and most reptiles are also oviparous. What do the eggs of both groups have in common?
- What traits are there in birds as a result of them being warm-blooded?

Introduction

We all think we know what a bird is. It seems fairly obvious. But if you were to really stop and think about birds, you would be amazed at the diversity of these organisms. From hummingbirds to ostriches, and countless varieties in between, birds are amazing creatures.

It is pretty easy to be aware of birds all around us. From pet birds in our houses to those seen flying and perching in the out-of-doors, birds constantly remind us of their diversity in both appearance and habits. Birds have special adaptations for flight, including feathers

and a lightweight skeleton. They also have a wide variety of reproductive strategies among the different types of birds. Let us examine some of their principle traits so we can get a better appreciation of what birds can do.

Characteristics of Birds

Birds (class Aves) are warm-blooded, vertebrate animals with two legs (bipedal), who lay eggs. They range in size from the tiny 2 in (5 cm) Bee Hummingbird to the 9 ft (2.7 m) ostrich (**Figure** 14.1). With approximately 10,000 living species, birds are the most numerous vertebrates with four limbs (tetrapod). They occur in diverse habitats across the globe, ranging from the Arctic to the Antarctic.

Figure 14.1: The ostrich can reach a height of 9 feet! Pictured here are ostriches with young in Namibia, Africa. (4)

Defining characteristics of modern birds include:

- feathers
- high metabolism
- a four-chambered heart
- a beak with no teeth
- a lightweight but strong skeleton
- production of hard-shelled eggs

The digestive system of birds is unique, with a crop for storage and a gizzard that contains swallowed stones for grinding food to compensate for the lack of teeth. Birds have forelimbs

modified as wings and nearly all can fly. Which of the above traits do you think might be of importance to flight?

Adaptations for Flight

In comparing birds with other vertebrates, what do you think distinguishes them the most? Of course, in most birds flight is the most obvious difference (**Figure** 14.2), and birds have adapted their body plan for this function. Their skeleton is especially lightweight, with large pneumatic (air-filled) cavities connecting to the respiratory system. Cervical, or neck, vertebrae are especially flexible and in birds with flight the sternum has a keel, or longitudinal ridge, for the attachment of two large flight muscles: the pectoralis, which encompasses 15% of the bird's total mass, and the supracoracoideus, the primary upstroke muscle for flight.

What other traits do you think might be important for flight? Of course, feathers are lightweight too and a forelimb modified as a wing serves as an aerofoil**.** This surface is designed to aid in lifting or controlling by making use of the air currents through which it moves. A bird's wing shape and size will determine how a species flies. For example, many birds have powered, flapping flight at certain times, while at other times they soar, using up less energy

Figure 14.2: One bird's flight, as seen in a tern species. (32)

About 60 living bird species are flightless, such as penguins, as were many extinct birds. Flightlessness often arises in birds on isolated islands, probably due to limited resources and the absence of land predators.

Reproduction in Birds

How do birds reproduce? We are all familiar with the classic chicken egg. So what is involved in the process of a bird laying an egg? It all starts with courtship. Courtship involves some type of courtship display, usually performed by the male, leading up to the breeding. Most displays involve a type of song and some displays are very elaborate and may include dancing, aerial flights, or wing or tail drumming.

One of the most distinguishing features of bird reproduction is internal fertilization and the laying of eggs. The hard-shelled eggs have a fluid-filled amnion, a thin membrane forming a closed sac around the embryo. Eggs are usually laid in a nest. How do you think where a bird lays an egg might influence the egg color? If an egg is hidden in a hole or burrow, away from predators, then the eggs are most often pale or white. Nests in the open have eggs that are camouflaged, thus giving protection against predation (**Figure** 14.3). However, some species like the ground-nesting nightjars, have pale eggs, but the birds themselves provide the camouflage with their feathers.

Figure 14.3: Nest and eggs of the common moorhen (*Gallinula chloropus*), showing camouflaged eggs. (30)

The shape of birds' nests varies quite a lot too. Most create somewhat elaborate nests, consisting of such structures as cups, domes, plates, mounds or burrows. The albatross, however, makes a nest that is simply a scrape on the ground. Still others, like the common guillemot, do not use nests, instead they lay their eggs on bare cliffs. The male emperor penguins are even more elaborate in the care of their eggs: they incubate the eggs between their body and feet.

How else might a bird help protect its young from predators? Most species locate their nests

in areas that are hidden, in order to avoid predators. Other birds that are large or nest in colonies may build nests in the open, since they are more capable of defending their young.

Young Birds and Parental Care

Parent birds usually incubate their eggs after the last one has been laid. In the 95% of species which are **monogamous,** (the species pair for the duration of the breeding season or sometimes for a few years or until one mate dies) the parents take turns incubating. In **polygamous** species, where there is more than one mate, one parent does all the incubating.

Brood parasitism, in which an egg-layer leaves her eggs in another individual's nest, is more common among birds than any other type of animal. The host bird often accepts and raises the parasite's eggs, at the expense of the host's own offspring.

Some precocial chicks, like those of the Ancient Murrelet (*Synthliboramphus antiquus*), follow their parents out to sea the night after they hatch, in order to avoid land predators. In most species, however, the young leave the nest just before, or right after, they can fly, sometimes making it necessary for them to walk until they have mastered flying.

The length and type of parental care varies widely amongst different species of birds. At one extreme in a group of birds called the magapodes, parental care ends in hatching. In this case, the newly-hatched chick digs itself out of the nest mound without parental help and can take care of itself right away. At the other extreme, many seabirds care for their young for extended periods of time, the longest being that of the Great Frigatebird, whose chicks take up to six months to fledge (getting parental care until they are ready to fly) and then an additional 14 months of being fed by the parents (**Figure** 14.4).

Although male parental care is rare among most groups of animals, in birds it is quite common, more so than in any other class of vertebrates. Often, the tasks of defense of territory and nest site, incubation, and feeding of chicks are shared between the parents; sometimes one parent undertakes all or most of a particular duty.

Given all the information so far about birds, what would you say is true about bird diversity?

Diversity of Birds

If you guessed that there is a lot of diversity in birds, you guessed correctly. About 10,000 bird species belong to 29 different orders, or groups, within the class Aves. They live and breed in most terrestrial habitats and on all seven continents. The greatest biodiversity of birds occurs in the tropics.

There is enormous diversity and a wide range of adaptations of various body parts, such as beaks and feet, to the specific habitats of the birds. There is also enormous diversity in the feeding habits of birds. The feeding habits of birds is related to the beak shape and size,

Figure 14.4: The Great Frigatebird (*Fregata minor*) adults are known to care for their young for up to 20 months after hatching, the longest in a bird species. Here, a young bird is begging for food. (12)

as well as the foot shape. Birds can be carnivores, insectivores, or **generalists**, which feed on a variety of foods. Some feed on nectar, such as hummingbirds. Can you think of some examples of beak shape and size that are adapted to the type of food a bird eats?

Beaks

For example, parrots and their allies have down-curved, hooked bills, which are well-adapted for cracking seeds and nuts, and eating the meat inside (**Figure** 14.5). Hummingbirds, on the other hand, have long, thin and pointed bills, which are ideal for probing tubular flowers for nectar (**Figure** 14.6). Can you also think of some different types of bird feet, which might be adapted for different types of habitats?

Feet

Webbed feet used for swimming or floating, as in waterfowl or gulls and terns, may come to mind (**Figure** 14.7). Other birds, for example, herons, gallinules and rails have four long spreading toes, which are ideal for walking delicately in the wetland in which they live (**Figure** 14.8). You can now see that you could come up with your own ideas for how a particular bird trait is adapted to a specific habitat, food, or other specialized requirement. That might even make going out for an outdoor hike more of an adventure!

Figure 14.5: The down-curved, hooked bill of a scarlet macaw, a large colorful parrot (*Ara macao*). (1)

Figure 14.6: A long, thin and pointed bill of the Swallow-tailed Hummingbird (*Eupetomena macroura*). (6)

Figure 14.7: The webbed feet of a great black-backed gull (*Larus marinus*). (33)

Figure 14.8: The long spreading toes of an American purple gallinule (*Porphyrio martinica*). (8)

Why Birds are Important

Now that you have some general knowledge about birds, you may want to make a list yourself of how you think birds are important. Just think about your daily living and how birds play a role. Do you eat chicken or turkey at meals? Do you have pet birds? Do you enjoy going out in your backyard or for a walk and listen to the beauty of birdsong or see the iridescent plumage of a bird in the sun?

What are some other economic uses of birds? One is the harvesting of guano (droppings) for use as fertilizer. Another is the use of chickens as an early warning system of diseases, such as West Nile Virus, that affect humans. In the latter example, mosquitoes carry the West Nile Virus, bite young chickens and other birds, and infect them with the virus. The first human cases of the virus usually follow the first appearance of infected birds within three months. Blood samples from young chickens can be tested for the presence of antibodies to the virus, and if detected, then this is an early warning that human infection can follow.

What about how birds can be important ecologically? For example, some nectar-feeding birds are important pollinators, and many frugivores, or fruit-eating birds, help disperse seeds. Birds are often important to island ecology, since they can easily reach islands. In New Zealand, the Kereru and Kokako are important browsers (animals that eat or nibble on leaves, tender young shoots, or other vegetation) and seabirds enrich the soil and water with their production of guano (**Figures** 14.9 and 14.10).

Figure 14.9: The Kereru is an important browser species in New Zealand. (15)

Finally, let's not forget that birds have had a relationship with humans since the dawn of humanity. Sometimes, as in the cooperative honey-gathering among honeyguides and African peoples such as the Borana, these relationships are mutualistic, where both benefit. Birds also play prominent and diverse roles in folklore, religion, and popular culture, and

Figure 14.10: The Kokako, another important browser species of New Zealand. (14)

have been featured in art since prehistoric times, as in early cave paintings. Perhaps their beauty and diversity will always capture the imagination of humans.

Lesson Summary

- Most of birds' traits are related to their being warm-blooded or their adaptations for flight.
- Adaptations for flight involve features that are lightweight, flexible, strong and that take advantage of air currents.
- The components of reproduction usually involve a courtship display, nest production, egg-laying, incubation and parental care. There is much diversity demonstrated in adaptations for predator avoidance.
- With 10,000 bird species there is a lot of diversity. Specialized structures are adapted for specific habitats or living requirements.
- Birds are important economically, ecologically and in human culture.

Review Questions

1. List five traits which are important for flight.
2. Describe how a bird's breeding system can be adapted to avoid predation.
3. Explain how the absence of land predators on islands would result in flightlessness in birds.
4. You detect the presence of antibodies to the West Nile Virus in young chickens. How did the chickens get the virus? When would the first human cases of the virus most likely occur?

Further Reading / Supplemental Links

- Department of Health, Florida. Available on the web at: www.doh.state.fl.us.
- Oliver L. Austin, Birds of the World. Western Publishing Company, Inc., New York, 1961.
- Unabridged Dictionary, Second Edition. Random House, New York, 1998.
- http://en.wikipedia.org/wiki/West_Nile_virus
- http://www.birds.cornell.edu/AllAboutBirds/studying
- http://kids.nationalgeographic.com/Animals
- http://www.ucmp.berkeley.edu/diapsids/birds/birdintro.html
- http://www.personal.psu.edu/users/h/j/hjs130/aves.html
- http://www.fs.fed.us/global/wings/birds.htm

Vocabulary

aerofoil A surface which is designed to aid in lifting or controlling by making use of the air currents through which it moves.

altricial A reproductive system in birds in which the newly hatched young are small, naked, immobile and blind.

monogamous A mating system in birds where the couple pair for the duration of the breeding season or sometimes for a few years or until one mate dies.

polygamous A mating system in birds where there is more than one mate.

precocial A reproductive system in birds in which the newly hatched young are feathered and mobile.

Points to Consider

- Birds and mammals are the only warm-blooded vertebrates. As in birds, mammals also have lots of diversity and live in varied habitats. Based on what you know about adaptations in birds, how do you think mammalian limbs are adapted for locomotion in different habitats?
- Mammals also have specialized diets, as in birds. Instead of beaks, mammals have different kinds of teeth. How do you think different kinds of teeth in mammals are adapted for different kinds of diets in this group?

14.2 Lesson 14.2: Mammals

Lesson Objectives

- List and describe general traits of mammals.
- Compare reproduction in monotremes, marsupials and placental mammals.
- Describe how mammals can be grouped according to their anatomy and their habitats.
- Explain how non-human mammals can benefit people and how they play an ecological role.

Check Your Understanding

- What traits are there in mammals as a result of them being warm-blooded?

Answer: They have fur to decrease heat loss; their diets contain high energy foods and methods of feeding help to maintain a high metabolism; and they conserve energy both by being inactive at certain times of day and sometimes by hibernation.

- Describe courtship displays in birds. As you learn about mammals, think about how their courtship is similar or different to that of birds.

Answer: Males usually perform courtship displays in birds. Most displays involve a type of song and some displays are very elaborate and may include dancing, aerial flights, or wing or tail drumming.

Introduction

What's a mammal? It is easy to forget about the biodiversity of mammals, but these animals range from bats and cats and rats to dogs and monkeys and whales. They walk and run and swim and fly. They live in the ocean, they fly in the sky, they walk on the prairies and run in the savannah. What allows them to live in such diverse environments? Well, mammals have some specialized traits which no other group of animals has. There is a tremendous amount of diversity within the group in terms of reproduction, habitat, and adaptation for living in their different habitats. It is because of some of their traits that mammals have been of benefit to people and also play an important ecological role.

Characteristics of Mammals

Mammals (class Mammalia) are warm-blooded, vertebrate animals with a number of unique characteristics. In most mammals, these include:

- The presence of hair
- Sweat glands
- Glands specialized to produce milk (**mammary glands**)
- Three middle ear bones
- A **neocortex** region in the brain
- Specialized teeth
- A four-chambered heart

All mammals, except for the **monotremes** (the most primitive order of mammals, with certain birdlike and reptilian characteristics, such as laying eggs, and a single opening for the urinary, genital, and digestive organs), produce live young (known as **vivipary**) instead of laying eggs.

There are approximately 5,400 mammalian species, ranging in size from the tiny 1-2 in (30-40mm) bumblebee bat to the 1,083ft (330m) blue whale. These are distributed in about 1,200 genera, 153 families and 29 orders. (see http://users.tamuk.edu/kfjab02/Biology/mammalogy/mammal_classification.htm).

Reproduction in Mammals

Keep in mind what you have learned about reptiles and birds and see how mammals might be both similar and different to these groups. The egg-laying monotremes, such as echidnas (**Figure** 14.11) and platypuses (**Figure** 14.12), use one opening, the cloacae, to urinate, deficate and reproduce, just as lizards and birds do. They lay leathery eggs, similar to those of lizards, turtles and crocodilians. Monochromes feed their young by "sweating" milk from patches on their bellies, since they lack nipples, unlike other mammals.

Figure 14.11: The echidna is a member of the monotremes, the most primitive order of mammals. (25)

All other mammals give birth to live young and are either marsupial or placental. The females of most **marsupials** have an abdominal pouch or skin fold within which are mammary glands and a place for raising the young (**Figure** 14.13). **Placental** mammals have a placenta that nourishes the fetus and removes waste products.

Some mammals are solitary except for brief periods when the female comes into **estrus,** the optimal time for a female to get pregnant. Others form social groups where a pronounced difference between sexes (sexual dimorphism) is frequently extreme. Dominant males are often those that are largest or best-armed. These males usually have an advantage in mating or may exclude other males from access to females within a group, such as in elephant seals (**Figure** 14.14). This group of females forms a **harem.** Think back to what you learned about courtship displays in birds. How are such systems in mammals similar or different?

Figure 14.12: Another monotreme, the platypus, like other mammals in this order, lays eggs and has a single opening for the urinary, genital, and digestive organs. (7)

Groups of Mammals

Mammal groups, as is true for most animal groups, can be characterized a number of ways. They can be characterized according to their anatomy, the habitats in which they live, and their feeding habits.

Most mammals belong to the placental group. Within this group are several subgroups including lagomorphs (i.e. hares and rabbits) and rodents (rats, mice and other small, gnawing mammals); carnivores (cats, dogs, bears and other mammals that are primarily meat eaters) (**Figure** 14.15); insectivores (including moles and shrews) (**Figure** 14.16); a group including bats and primates; and ungulates (hoofed animals, including deer, sheep, goats, buffalo and elephants, and also whales and manatees) (**Figure** 14.17).

Why do you think the above groups of animals are placed together? Can you think of some examples of tooth type that are adapted for a mammals' diet and types of limbs that are adapted for living in different types of habitats?

Mammals can also be grouped according to the habitat they live in and with adaptations for living in that habitat. Terrestrial mammals with saltatory (leaping) locomotion, as in some marsupials and in lagomorphs, is typically found in mammals living in open habitats. Other terrestrial mammals are adapted for running, such as dogs or horses. Still others, such as elephants, hippopotamuses and rhinoceroses, have a cumbersome (and hefty) mode of locomotion known as "graviportal."

Other mammals are adapted for living in trees (arboreal), such as many New World monkeys (**Figure** 14.18). Others are fully aquatic, such as manatees, whales, dolphins and seals, and others are adapted for flight, as are bats, or gliding (some marsupials and rodents).

Figure 14.13: A marsupial mammal, this Eastern grey kangaroo has a joey (young kangaroo) in its abdominal pouch. (28)

Figure 14.14: A mating system with a harem of many females and one male, as seen in the seal species, *Callorhinus ursinus*. (18)

Figure 14.15: A Caracal, hunting in the Serengeti. (11)

Figure 14.16: One of the subgroups of placental mammals is the insectivores, including moles and shrews. Pictured here is the Northern short-tailed shrew. (10)

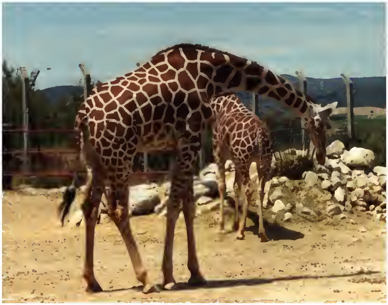

Figure 14.17: The ungulates (hoofed animals) like the giraffe here, is another of the subgroups belonging to the placental mammals. (20)

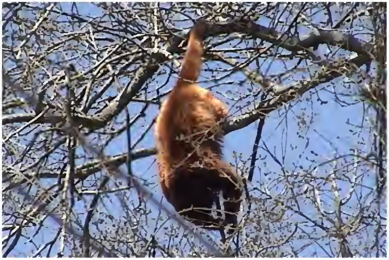

Figure 14.18: This howler monkey shows adaptations for an arboreal existence. (9)

Significance of Mammals

Mammals are thought to be significant both in terms of how they benefit people and also of their importance ecologically. Given what you know about mammals so far, how do you think they may be important to people? Just examining our daily lives we see examples of mammals (other than people!) serving our needs everywhere. We have pets that are mammals, most commonly dogs and cats; if we live in rural areas or visit another country we will probably see lots of examples of mammals used for transport (horses, donkeys, mules and even camels), being raised for food (cows and goats), and used for work (dogs (**Figure** 14.19), horses, and elephants).

The special capabilities of some mammal species have been used in practical situations and also to increase our knowledge. Can you think of how they have been used? For example, the United State and Russian militaries have trained and employed oceanic dolphins to rescue lost divers or to locate underwater mines. Mammals' more highly developed brain has made them ideal for use by scientists in studying such things as learning, as seen in maze studies of mice and rats. The ability of young mammals to learn from the experience of their elders has allowed a behavioral plasticity unknown in any other group of organisms and has been a primary reason for the evolutionary success of mammals. See if you can come up with some other examples.

Mammals have also played a significant role in different cultures' folklore and religion. For example, the grace and power of the cougar have been widely admired in the cultures of the indigenous peoples of the Americas. The Inca city of Cusco is reported to have been designed in the shape of a cougar and the sky and thunder god of the Inca, Viracocha, has been associated with the animal. In North America, mythological descriptions of the cougar have appeared in stories of a number of Native American tribes.

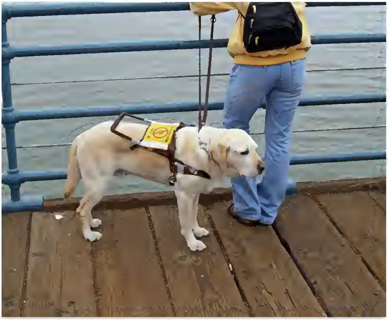

Figure 14.19: A Labrador Retriever working as an assistance dog. (17)

Ecologically, nectar-feeding and fruit-eating bats (**Figure** 14.20) play an important role in plant pollination and seed dispersal, respectively. Can you think of a type of bird that has a similar ecological role?

Mammals are also the only animal group that has made a complete transition to aquatic habitats. Some, such as cetaceans (whales, dolphins and porpoises) have undergone profound adaptations for swimming and life, even reproduction, in the water. Cetaceans depend on water for mechanical support and thermal insulation. Because they are buoyed by their aquatic environment, whales have evolved into the largest mammals and the largest animals ever recorded.

Micro-Lab: Matching Adaptations of Teeth and Limbs in Mammals with their respective Diets and Habitats

Estimated time: 15 minutes

Materials:

1. Tray of actual, or illustrations of, various mammal teeth, numbered, and Pictures of animals eating:

- Incisors – cutting and nipping (herbivores, like cows, have well-developed incisors for cutting grass)

Figure 14.20: Bats, like this Egyptian fruit bat, belong to another subgroup of placental mammals. Ecologically, fruit bats play an important role in seed dispersal. (24)

- Premolars – shearing and grinding (herbivores, like cows, have flat premolars and molars for grinding vegetation)
- Canines – piercing (carnivores, like lions, have long and strong canines.)

2. Tray of actual, or illustrations of, various mammalian limbs, numbered (for feet, could also show cast of track, to see if students can match the track with the actual foot type) and pictures of habitats or actual animals, lettered:

- Toe ending in claws – tiger (climbing and running)
- Toes with hooves – horses and cows (running)
- Fins – aquatic mammals (swimming)
- Wings – bats (flying)
- Highly mobile limbs – monkeys (climbing in trees)

3. Answer sheets, listing numbered mammal teeth and limbs

Directions:

One group of students examines the tray of mammal teeth and pictures of diets and indicates on the answer sheet the correct matches. The other group of students examines the tray of mammal limbs and pictures of habitats and similarly matches these up with the correct answers.

Links to websites with pictures of mammal teeth and/or limbs: Teeth:

http://www.vinsweb.org/education/elf/units/tas.html

http://www.teachersdomain.org/resources/tdc02/sci/life/stru/jaws/index.html

Teeth and Limbs:

http://www.acornnaturalists.com/Mammal-Activities-C227.aspx

Lesson Summary

- The class Mammalia is distinguished by the presence of hair, sweat glands, three middle ear bones and a neocortex area in the brain.
- There is a lot of variation in mammalian reproductive systems. Mammals consist of both the egg-laying monotremes and those that are viviparous. The latter group includes marsupial and placental mammals. Diversity can also be found in mammalian mating systems.
- The 5,400 species of mammals can be grouped according to anatomical features as well as the type of habitat found in. Mammals have specific adaptations for living on land, in trees, in water and for flight.
- Non-primate mammals have an important relationship with people as well as fulfilling necessary ecological functions.

Review Questions

1. What are two ways in which monotremes differ from viviparous mammals?
2. With respect to characteristics of feet, limbs and tails, what features would you expect mammals to have for
   (a) jumping?
   (b) living in trees?
3. Give examples of three different adaptations of limbs for locomotion in mammals, naming a mammal species, a structure and how it is adapted.
4. Instead of beaks, as in birds, mammals have different kinds of teeth. Incisors are specialized for cutting and nipping, premolars for shearing and grinding, and canines for piercing. Based on what you know of diets in mammals, name two mammal species, the kind of diet they eat, and one type of specialized teeth that would be best adapted for the diet.
5. In order to maintain a high constant body temperature, mammals need a nutritious and plentiful diet. What are some ways that mammals have adapted to meet their dietary requirements? How might size determine diet type, and why?

Further Reading / Supplemental Links

- Unabridged Dictionary, Second Edition. Random House, New York, 1998.
- http://en.wikipedia.org
- http://kids.nationalgeographic.com/Animals
- http://kids.yahoo.com/animals/mammals
- http://nationalzoo.si.edu/Animals/SmallMammals/ForKids
- http://www.ucmp.berkeley.edu/mammal/mammal.html
- http://www.americazoo.com/goto/index/mammals/classification.htm

Vocabulary

estrus A period of time when the female has maximum sexual receptivity.

harem A group of females followed or accompanied by a fertile male; this male excludes other males access to the group.

mammary glands Specialized sweat glands that produce milk.

marsupial A type of mammal where the female has an abdominal pouch or skin fold within which are mammary glands and a place for raising the young.

monotremes A group of mammals that lays eggs and feeds their young by "sweating" milk from patches on their bellies.

neocortex Site of the cerebral cortex where most of higher brain functions occur.

placental A type of mammal that has a placenta that nourishes the fetus and removes waste products.

vivipary A reproductive system in most mammals and some reptiles and fish, in which living young are produced rather than eggs laid.

Points to Consider

- Rats are considered to be highly intelligent as they can learn and perform new tasks, an ability that may be important when they first colonize a fresh habitat. Think about what kind of increased learning takes place with an increased brain size, as we will see in primates.
- Think of some significant similarities between the mammals you read about in this lesson with those in the next lesson, particularly human beings.
- What are some significant adaptations in the evolution of primates?

14.3 Lesson 14.3: Primates and Humans

Lesson Objectives

- List and describe general traits of primates.
- Summarize mating systems of primates.
- Review the types of habitats primates can be found in.
- Describe the three main groupings of primates.
- List the traits of the hominids, their diet, reproduction and social system.

Check Your Understanding

- What are general traits of mammals?
- Describe the mating systems in mammals.

Introduction

If primates are mammals, what makes them seem so different? Primates, including humans, have several unique features only belonging to this group of mammals. Some of these adaptations are obvious, others not so obvious. Some of these features give primates advantages such that allow them to live in certain habitats, such as arboreal habitats, such as trees. Other features have allowed them to adapt to complex and new social and cultural situations.

What are Primates?

The biological order Primates, mostly **omnivorous** (eating both plant and animal material) mammals, contains all the species commonly related to the lemurs (**Figure** 14.21), monkeys (**Figure** 14.22) and apes ((**Figure** 14.23), the latter including humans ((**Figure** 14.24). All primates have five fingers (**pentadactyl**), a generalized dental pattern, a primitive (nonspecialized) body plan and certain eye orbit characteristics, such as a postorbital bar (a bone, which runs around the eye socket). While an opposable thumb (the only digit on the hand able to turn back against the other four fingers, thereby refining the grip in order to hold objects) are a characteristic feature of this group, other orders, such as opossums, also have this feature.

In intelligent mammals, such as primates, the cerebrum is larger relative to the rest of the brain. Indications of intelligence in primates include the ability to learn and complex behavioral flexibility, involving much social interaction, such as fighting and play.

Old World species (apes and some monkeys as seen in **Figure** 14.25) tend to have signifi-

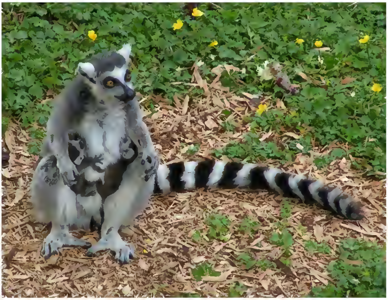

Figure 14.21: A ring tailed lemur and twins. Lemurs belong to the prosimian group of primates. (22)

Figure 14.22: One of the New World monkeys, a squirrel monkey. (2)

Figure 14.23: Chimpanzees, pictured here, belong to the great apes, one of the groups of primates. (27)

cant **sexual dimorphism,** characterized mostly as size differences, with males being slightly more than twice as heavy as females. This dimorphism may be a result of a polygamous mating system where males attract and defend multiple females. New World species (including tamarins((**Figure** 14.26) and marmosets(**Figure** 14.27)) form pair bonds, which is a partnership between a mating pair that lasts at least one season. The pair cooperatively raise the young, and thus generally do not show significant size difference between the sexes.

Non-human primates occur mostly in Central and South America, Africa and South Asia. Since primates evolved from arboreal animals, many modern species live mostly in trees. Other species are partially terrestrial, such as baboons (**Figure** 14.28) and the Patas monkey. Only a few species are fully terrestrial, for example, the gelada and humans.

Primates live in a diverse number of forested habitats, including rain forests, mangrove forests and mountain forests to altitudes of over 9,800 ft (3,000 m). The combination of opposable thumbs, short fingernails and long, inward-closing fingers has, in part, allowed some species to develop brachiation, locomotion of swinging by arms from one branch to another (**Figure** 14.29). Another feature for climbing – expanded digits – as in tarsiers improves grasping (**Figure** 14.30).

A few species, such as the proboscis monkey, De Brazza's monkey and Allen's swamp monkey, the latter having small webbing between its fingers, are fine swimmers and occur in swamps and other aquatic habitats. Some species, such as the rhesus macaque and the Hanuman langur, can exploit human-altered environments and even live in cities.

Figure 14.24: Reconstruction of a Neanderthal man, belonging to an extinct subspecies of *Homo sapiens*, humans, who are part of the great apes. This subspecies lived in Europe and western and central Asia from about 100,000 – 40,000 B.C. (26)

Figure 14.25: An Old World monkey, a species of macaque, in Malaysia. (21)

Figure 14.26: A New World species of monkey, a tamarin. (13)

Figure 14.27: Another New World species of monkey, the common marmoset. (3)

Figure 14.28: Baboons are partially terrestrial. Pictured here is a mother baboon and her young, in Tanzania. (19)

Figure 14.29: A gibbon shows how its limbs are modified for hanging from trees. (5)

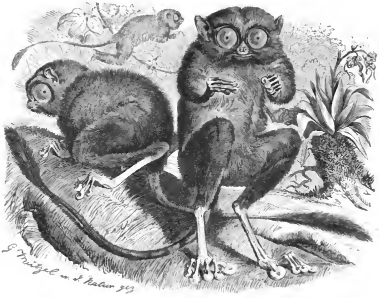

Figure 14.30: A species of tarsier, with expanded digits used for grasping branches. (31)

Primate Classification

The primate order is divided informally into three main groupings: prosimians, New World monkeys, and Old World monkeys and the apes. The prosimians are species whose bodies most closely resemble that of the early proto-primates, the earliest examples of primates (**Figure** 14.31). Prosimians include the lemurs, located in Madagascar and to a lesser extent on the Comoro Islands, a group of islands in the Indian Ocean.

Figure 14.31: One of the prosimians, a greater bush baby, Kenya. (23)

The New World monkeys include the capuchin, howler and squirrel monkeys, who live exclusively in the Americas. The Old World monkeys and the apes (all except for humans, who inhabit the entire earth) inhabit Africa and southern and central Asia.

A few new species of primates are discovered each year and the evaluation of current populations varies as to the number of species; estimates over the last several years range from 350 to 405 species. In New World monkeys alone there are thought to be 128 species; of Old World monkeys, 135 species; of gibbons or "lesser apes," 13 species and of humans and other great apes, seven species. But there is only one species of humans, which will be discussed below.

The Human Family

The great apes are the members of the biological family Hominidae, which includes seven species, making up humans, two species each of chimpanzees, gorillas and orangutans. Hominids are large, tailless primates, ranging in size from the pygmy chimpanzee, at 66-88 lbs (30-40 kg) in weight, to the gorilla, at 309-397 lbs (140-180 kg) (**Figure** 14.32). In all

species, the males are, on average, larger and stronger than the females, although the degree of sexual dimorphism varies greatly. Most living species are predominantly **quadrupedal** (four-footed), but all are able to use their hands for gathering food or nesting materials, and in some cases, for using tools, such as gorillas using sticks to gauge the depth of water and chimpanzees sharpening sticks to use as spears in hunting and using sticks to gather food and to "fish" for termites (**Figure** 14.33).

Figure 14.32: A gorilla mother and baby, members of the great apes, at Volcans National Park, Rwanda. The gorilla is the largest of the hominids, getting up to 309-397 lbs. (29)

Most species are omnivorous (eat both plants and meat), but fruit is the preferred food among all but humans. In contrast, humans consume a large proportion of highly processed, low fiber foods, unusual proportions of grains and vertebrate meat, as well as a wide variety of other foodstuffs. Human teeth and jaws are markedly smaller for our size than those of other apes, perhaps as adaptations to eating cooked food. Humans may have been eating cooked food for possibly as long as a million years or more.

Gestation lasts 8-9 months and usually results in the birth of a single offspring. The young are born helpless, and thus they need parental care for long periods of time. Compared with most other mammals, great apes have a long adolescence and become fully mature not until 8-13 years in most species (longer in humans). Thus, females typically give birth only once every few years.

Gorillas and chimpanzees live in family groups of approximately five to ten individuals, although larger groups are sometimes observed. The groups include at least one dominant male, and females leave the group at maturity. Orangutans, however, are generally solitary. Human social structure is complex and highly variable. Can you think of any that are similar to those of other great apes?

Gorillas, chimpanzees and humans are all lumped together in the subfamily, the Homininae,

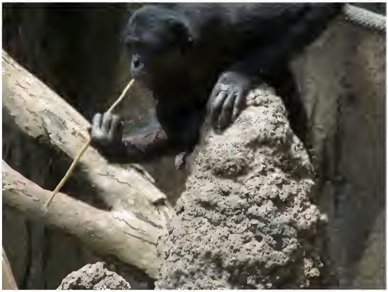

Figure 14.33: Tool using in a primate. A chimpanzee uses a stick to "fish" for termites, and then, pictured here, extracts the insects. (16)

because they generally share more than 97% of their DNA with each other, and exhibit a capacity for language or for simple culture beyond the family or band, a group of animals functioning together. A proposed theory including such faculties as empathy is a controversial criterion distinguishing the adult human alone among the hominids. Can you think of other human attributes that are unique to humans?

Lesson Summary

- Primates are characterized by pentadactyly, a generalized dental pattern, a nonspecialized body plan and certain eye orbit features. Primates also have opposable thumbs and a large cerebrum relative to the rest of the brain.
- Old World species tend to have significant sexual dimorphism, whereas New World species generally do not show significant sexual differences.
- Many primates live in a variety of forested habitats, whereas others are partially terrestrial, and some, like the gelada and humans, are fully terrestrial. A few species are adapted for living in aquatic habitats.
- There are three subgroups within the primates order: prosimians, including the lemurs; New World monkeys, and the Old World monkeys and the apes. There are estimated to be somewhere between 350 to 405 species of primates.
- The great apes, consisting of seven species, are large, tailless primates, with sexual dimorphism. Most species are quadrupedal, but all are able to use their hands.
- Most great apes are omnivorous, but fruit is the preferred food among all species but

humans.
- The great apes have unique reproductive and parental care features, especially when compared with most other mammals. There is a variety of social structure among the great apes.
- Gorillas, chimpanzees and humans share some common characteristics.

Review Questions

1. What characteristics distinguish the biological order Primates?
2. What theory might explain why human teeth and jaws are markedly smaller for our size than those of other apes?
3. Opposable thumbs are a characteristic primate feature. List two ways in which non-human primates might use opposable thumbs.
4. Various hybrid monkeys are produced in captivity when different species or subspecies are housed together. In what situation in the wild would hybrids be produced?
5. Primates are thought to have developed several of their traits and habits initially while living in trees. What primate features might be an advantage in an arboreal habitat?
6. Gorillas and chimpanzees live in family groups of around five to 10 individuals. What are two possible strategies for feeding, when fruit is hard to find?

Further Reading / Supplemental Links

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- http://www.ucmp.berkeley.edu/mammal/eutheria/primates.html
- http://pslc.ws/macrog/paul/lemurs.htm
- http://www.wikipedia.org

Vocabulary

hybrid The offspring of different species, genera, varieties or breeds.

omnivorous Eating both plant and animal material.

pentadactyl Having five fingers or toes.

quadrupedal Four-footed

sexual dimorphism A condition in which the males and females of a species are different in form and structure.

Points to Consider

- Forward-facing color binocular vision was useful for human ancestors who swung by their arms from one branch to another. Recent studies suggest this type of vision was more useful in courtship. What other groups of animals might vision also be important in courtship?
- Thousands of primates are used every year around the world in scientific experiments because of their psychological and physiological similarity to humans. What kinds of behavioral experiments do you think might be conducted in primates?

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Chapter 15

Behavior of Animals

15.1 Lesson 15.1: Understanding Animal Behavior

Lesson Objectives

- Give examples of animal behavior.
- Explain why animal behavior is important.
- Describe innate behavior and how it evolves.
- List ways that behavior can be learned.

Check Your Understanding

- What is an animal?
- Give examples of a wide variety of animals.

Do you have a dog or a cat? If you don't, you probably know someone that does. Think about how these animals act. Does the dog bark when it's excited? Does the cat purr when it's happy? Do they both play with toys?

Examples of Animal Behavior

Barking, purring, and playing are just some of the ways that dogs and cats behave. These are examples of animal behavior. **Animal behavior** is any way that animals act, either alone or with other animals. Can you think of other examples of animal behavior? What about insects and birds? How do they behave? The pictures in **Figures** 15.1, 15.2, 15.3, 15.4, 15.5, 15.6 and 15.7 show some of the ways that these and other animals act. Look at the pictures and read about the behaviors.

All of the animals pictured in the **Figures** here are busy doing something important. Read about what each animal is doing. Think about why the animal is behaving that way. These are just a few of the many ways that animals behave.

Figure 15.1: This cat is stalking a mouse. It is a hunter by nature. (16)

Importance of Animal Behavior

Why do animals behave in these ways? The answer to this question depends on what the behavior is. A cat chases a mouse to catch it. A spider spins its sticky web to trap insects. A mother dog nurses her puppies to feed them. All of these behaviors have the same purpose: getting or providing food. All animals need food for energy. They need energy to move around. In fact, they need energy just to stay alive. Baby animals also need energy to grow and develop.

Birds and wasps build nests to have a safe place to store their eggs and raise their young. Many other animals build nests for the same reason. Animals protect their young in other

Figure 15.2: This spider is busy spinning a web. If you have ever walked into a spider web, you know how sticky a spider web can be. Why do spiders spin webs? (4)

Figure 15.3: This mother dog is nursing her puppies. In what other ways do mother dogs care for their puppies? (7)

Figure 15.4: This bird is using its beak to add more grass to its nest. What will the bird use its nest for? (5)

Figure 15.5: This wasp is starting to build a nest. Have you seen nests like this on buildings where you live? Why do wasps build nests? (14)

Figure 15.6: This rabbit is running away from a fox. Did you ever see a rabbit run? Do you think you could run that fast? (20)

Figure 15.7: This lizard is perched on a rock in the sun. Lizards like to lie on rocks and "sun" themselves. Do you know why? (24)

ways, as well. For example, a mother dog not only nurses her puppies. She also washes them with her tongue and protects them from strange people or other animals. All of these behaviors help the young survive and grow up to be adults.

Rabbits run away from foxes and other predators to stay alive. Their speed is their best defense. Lizards sun themselves on rocks to get warm because they cannot produce their own body heat. When they are warmer, they can move faster and be more alert. This helps them escape from predators, as well as find food.

All of these animal behaviors are important. They help the animals get food for energy, make sure their young survive, or ensure that they survive themselves. Behaviors that help animals or their young survive increase the animals' fitness. You read about fitness in the *Evolution* chapter. Animals with higher fitness have a better chance of passing their genes to the next generation. If behaviors that increase fitness are controlled by genes, the behaviors become more common in the species. This is called evolution by natural selection.

Innate Behavior

All of the behaviors shown in **Figures** 15.1, 15.2, 15.3, 15.4, 15.5, 15.6 and 15.7 are ways that animals act naturally. They don't have to learn how to behave in these ways. Cats are natural-born hunters. They don't need to learn how to hunt. Spiders spin their complex webs without learning how to do it from other spiders. Birds and wasps know how to build nests without being taught. Behaviors such as these are called innate.

An **innate behavior** is any behavior that occurs naturally in all animals of a given species. An innate behavior is also called an **instinct**. The first time an animal performs an innate behavior, the animal does it well. The animal does not have to practice the behavior in order to get it right or become better at it. Innate behaviors are also predictable. All members of a species perform an innate behavior in the same way. From the examples described above, you can probably tell that innate behaviors usually involve important actions, like eating and caring for the young.

There are many other examples of innate behaviors. For example, did you know that honey bees dance? The honey bee in **Figure** 15.8 has found a source of food. When the bee returns to its hive, it will do a dance, called the waggle dance. The way the bee moves during its dance tells other bees in the hive where to find the food. Honey bees can do the waggle dance without learning it from other bees, so it is an innate behavior.

Besides building nests, birds have other innate behaviors. One example occurs in gulls. A mother gull and two of her chicks is shown in **Figure** 15.9. One of the chicks is pecking at a red spot on the mother's beak. This innate behavior causes the mother to feed the chick. In many other species of birds, the chicks open their mouths wide whenever the mother returns to the nest. This is what the baby birds in **Figure** 15.10 are doing. This innate behavior, called gaping, causes the mother to feed them.

Figure 15.8: When this honey bee goes back to its hive, it will do a dance to tell the other bees in the hive where it found food. (27)

Figure 15.9: This mother gull will feed her chick after it pecks at a red spot on her beak. Both pecking and feeding behaviors are innate. (2)

Figure 15.10: When these baby birds open their mouths wide, the mother instinctively feeds them. This innate behavior is called gaping. (15)

Another example of innate behavior in birds is egg rolling. It happens in some species of water birds, like the graylag goose shown in **Figure** 15.11 . Graylag geese make nests on the ground. If an egg rolls out of the nest, a mother goose uses her bill to push it back into the nest. Returning the egg to the nest helps ensure that the egg will hatch.

Drawback of Innate Behavior

Innate behaviors such as these usually help animals or their offspring survive. Therefore, they increase fitness. This is why the behaviors evolved. However, innate behaviors have a drawback. The trouble with innate behaviors is that they are not flexible. An innate behavior is always performed exactly the same way.

The example of the graylag goose shows how this can be a problem. The sight of any nearby egg-shaped object will cause a graylag goose to push the object into her nest. She will push the object even if it isn't an egg. For example, if the mother goose sees a golf ball nearby, she will push it into her nest. This wastes time and energy that could be spent on the real eggs. From this example, you can see that innate behavior is not always helpful. It does not always increase fitness.

Figure 15.11: This female graylag goose is a ground-nesting water bird. Behind her are two of her young chicks. Before the chicks hatch, the mother protects the eggs. She will use her bill to push eggs back into the nest if they roll out. This is an example of an innate behavior. How could this behavior increase the mother goose's fitness? (8)

Innate Behavior in Human Beings

All animals have innate behaviors, even human beings. Can you think of human behaviors that do not have to be learned? Chances are, you will have a hard time thinking of any. The only truly innate behaviors in humans are called **reflex behaviors**. They occur mainly in babies. Like innate behaviors in other animals, reflex behaviors in human babies may help them survive.

An example of a reflex behavior in babies is the sucking reflex. Newborns instinctively suck on a nipple that is placed in their mouth. It is easy to see how this behavior evolved. It increases the chances of a baby feeding and surviving.

Another example of a reflex behavior in babies is the grasp reflex. This behavior is shown in **Figure** 15.12. Babies instinctively grasp an object placed in the palm of their hand. Their grip may be surprisingly strong. How do you think this behavior might increase a baby's chances of surviving?

Learned Behavior

Just about all other human behaviors are learned and not innate. **Learned behavior** is behavior that occurs only after experience or practice. Learned behavior has an advantage over innate behavior. It is more flexible. Learned behavior can be changed if conditions change. For example, you probably know the route from your house to your school. Assume that you moved to a new house in a different place, so you had to take a different route to school. What if following the old route was an innate behavior? You would not be able to adapt. Fortunately, it is a learned behavior. You could learn the new route just as you learned the old one.

Although most animals can learn, animals with greater intelligence are better at learning and have more learned behaviors. Humans are the most intelligent animals. They depend on learned behaviors more than any other species. Other highly intelligent species include the apes, our closest relatives in the animal kingdom. You read about apes in the previous chapter. They include chimpanzees and gorillas. Both are also very good at learning behaviors.

You may have heard of a gorilla named Kook. Koko was raised by the psychologist Dr. Francine Patterson. Dr. Patterson wanted to find out if gorillas could learn human language. Starting when Koko was just one year old, Dr. Patterson taught her to use sign language. Koko learned to use and understand more than 1,000 signs. Koko showed how much gorillas can learn.

Think about some of the behaviors you have learned. They might include riding a bicycle, using a computer, and playing a musical instrument or sport. You probably did not learn all of these behaviors in the same way. Perhaps you learned some behaviors on your own, just by practicing. Other behaviors you may learned from other people. Humans and other

Figure 15.12: One of the few innate behaviors in human beings is the grasp reflex. It occurs only in babies. (10)

animals can learn behaviors in several different ways. Some common ways of learning are habituation, observational learning, conditioning, play, and insight learning.

Habituation

Habituation is learning to get used to something after being exposed to it for awhile. Habituation usually involves getting used to something that is annoying or frightening but not dangerous. Habituation is one of the simplest ways of learning. It occurs in just about every species of animal.

You have probably learned through habituation many times. For example, maybe you were reading a book when someone turned on a television in the same room. At first, the sound of the television may have been annoying. After awhile, you may no longer have noticed it. If so, you had become habituated to the sound.

Another example of habituation is shown in **Figure** 15.13. Crows and most other birds are usually afraid of people. They avoid coming close to people, or they fly away when people come near them. The crows landing on this scarecrow have gotten used to a "human" in this place. They have learned that the scarecrow poses no danger. They are no longer afraid to come close. They have become habituated to the scarecrow.

Can you see why habituation is useful? It lets animals ignore things that will not harm them. Without habituation, animals might waste time and energy trying to escape from things that are not really dangerous.

Observational Learning

Observational learning is learning by watching and copying the behavior of someone else. Human children learn many behaviors this way. When you were a young child, you may have learned how to tie your shoes by watching your dad tie his shoes. More recently, you may have learned how to dance by watching a pop star dancing on TV. Most likely you have learned how to do math problems by watching your teachers do problems on the board at school. Can you think of other behaviors you have learned by watching and copying other people?

Other animals also learn through observational learning. For example, young wolves learn to be better hunters by watching and copying the skills of older wolves in their pack. Another example of observational learning is how some monkeys have learned how to wash their food in the ocean. They learned by watching and copying the behavior of other monkeys.

Figure 15.13: This scarecrow is no longer scary to these crows. They have gotten used to it being in this spot and learned that it is not dangerous. This is an example of habituation. (11)

Conditioning

Conditioning is a way of learning that involves a reward or punishment. Did you ever train a dog to fetch a ball or stick by rewarding it with treats? If you did, you were using conditioning. Another example of conditioning is shown in **Figure** 15.14. This lab rat has been taught to "play basketball" by being rewarded with food pellets. Conditioning also occurs in wild animals. For example, bees learn to find nectar in certain types of flowers because they have found nectar in those flowers before.

Figure 15.14: This rat has been taught to put the ball through the hoop by being rewarded with food for the behavior. This is an example of conditioning. What do you think would happen if the rat was no longer rewarded for the behavior? (28)

Humans learn behaviors through conditioning, as well. A young child might learn to put away his toys by being rewarded with a bedtime story. An older child might learn to study for tests in school by being rewarded with better grades. Can you think of behaviors you learned by being rewarded for them?

Did you ever hear the saying, "You can't teach an old dog new tricks?" Don't believe it. Older dogs—like older people—are capable of learning new behaviors. They may learn more slowly, but they can still learn to behave in new ways.

Conditioning does not always involve a reward. It can involve a punishment instead. A toddler might be punished with a time-out each time he grabs a toy from his baby brother. After several time-outs, he may learn to stop taking his brother's toys. A dog might be scolded each time she jumps up on the sofa. After repeated scolding, she may learn to stay off the sofa. A bird might become ill after eating a poisonous insect. The bird may learn from this "punishment" to avoid eating the same kind of insect in the future.

Learning by Playing

Most young mammals—including humans—like to play. Play is one way they learn skills they will need as adults. Think about how kittens play. They pounce on toys and chase each other. This helps them learn how to be better predators when they are older. Big cats also play. The lion cubs in **Figure** 15.15 are playing and practicing their hunting skills at the same time. The dogs in **Figure** 15.16 are playing tug-of-war with a toy. What do you think they are learning by playing together this way? Other young animals play in different ways. For example, young deer play by running and kicking up their hooves. This helps them learn how to escape from predators.

Human children learn by playing, as well. For example, playing games and sports can help them learn to follow rules and work with others. The baby in **Figure** 15.17 is playing in the sand. She is learning about the world through play. What do you think she might be learning?

Insight Learning

Insight learning is learning from past experiences and reasoning. It usually involves coming up with new ways to solve problems. Insight learning generally happens quickly. An animal has a sudden flash of insight.

Insight learning requires relatively great intelligence. Human beings use insight learning more than any other species. They have used their intelligence to solve problems ranging from inventing the wheel to flying rockets into space. Think about problems you have solved. Maybe you figured out how to solve a new type of math problem or how to get to the next level of a video game. If you relied on your past experiences and reasoning to do it, then

Figure 15.15: These two lion cubs are playing. They are not only having fun. They are also learning how to be better hunters. (31)

Figure 15.16: They are really playing. This play fighting can help them learn how to be better predators. (1)

Figure 15.17: Playing in a sandbox is fun for young children. It can also help them learn about the world. For example, this child may be learning that sand is soft. (23)

you were using insight learning.

One type of insight learning is making tools to solve problems. Scientists used to think that humans were the only animals intelligent enough to make tools. In fact, being able to make tools was thought to be one of the most important human traits. Tool making was believed to set humans apart from all other animals. Then, in 1960, chimpanzee expert Jane Goodall discovered that chimpanzees also make tools. She saw a chimpanzee strip leaves from a twig. Then he poked the twig into a hole in a termite mound. After termites climbed onto the twig, he pulled the twig out of the hole and ate the insects clinging to it (**Figure** 15.18). The chimpanzee had made a tool to "fish" for termites. He had used insight to solve a problem.

Figure 15.18: This chimpanzee was the first nonhuman primate ever observed to make tools. He was studied by Jane Goodall. He is eating termites from the "fishing pole" he made from a twig. (22)

Since then, chimpanzees have been seen making several different types of tools. For example, they sharpen sticks and use them as spears for hunting. They use stones as hammers to crack open nuts. Scientists have also observed other species of animals making tools to solve problems. A crow was seen bending a piece of wire into a hook. Then the crow used the hook to pull food out of a tube. An example of a gorilla using a walking stick is shown in **Figure** 15.19. Behaviors such as these show that other species of animals—not just humans—can use their experience and reasoning to solve problems. They can learn through insight.

Figure 15.19: This gorilla is using a branch as a tool. She is leaning on it to keep her balance while she reaches down into swampy water to catch a fish. (17)

Lesson Summary

- Animal behavior is any way that animals act, either alone or with other animals.
- Behaviors that increase fitness can evolve through natural selection.
- Innate behavior is behavior that occurs naturally in all members of a species.
- Learned behavior is behavior that occurs only after experience or practice.

Review Questions

Knowledge and Comprehension

1. Give two examples of animal behavior.
2. Define innate behavior.
3. Identify one drawback of innate behavior.
4. What is learned behavior?
5. State three ways that behavior can be learned.

Critical Thinking

1. Explain how egg rolling by graylag geese is likely to have evolved.
2. Describe how the grasp reflex might help a baby survive.
3. Explain how you could use conditioning to teach a dog to sit.
4. Why is play important for baby animals?
5. A crow was seen dropping nuts on a rock to crack the shells and then eating the nut meats. No other crows in the flock were ever observed cracking nuts in this way. What type of learning could explain the behavior of this crow?

Further Reading / Supplemental Links

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Vocabulary

animal behavior Any way that animals act, either alone or with other animals.

innate behavior Any behavior that occurs naturally in all animals of a given species.

instinct Another term for an innate behavior.

reflex behaviors The only truly innate behaviors in humans, occurring mainly in babies.

learned behavior Behavior that occurs only after experience or practice.

habituation Learning to get used to something that is not dangerous after being exposed to it for awhile.

observational learning Learning by watching and copying the behavior of someone else.

conditioning Way of learning that involves a reward or punishment.

insight learning Learning from past experiences and reasoning.

Points to Consider

Did you ever watch a long line of ants marching away from their ant hill? What were they doing? How were they able to work together? What explains group behaviors such as this?

15.2 Lesson 15.2: Types of Animal Behavior

Lesson Objectives

- List ways that animals communicate.
- Describe social behavior in animals.
- Explain the purpose of mating behavior.
- Describe how animals defend their territory.
- Identify animal behaviors that occur in cycles.

Check Your Understanding

- What is an animal?
- Give examples of a wide variety of animals.
- List some "behaviors" animals, such as spiders and rabbits, have in common.

Introduction

What is reproduction? (Reproduction is the production of offspring. Animals reproduce asexually or sexually. Reproduction is related to fitness because fitness depends in part on the ability to reproduce. Do all animals talk to each other? Probably not, but many do communicate. Like human beings, many other animals live together in groups. Some insects, including ants and bees, are well known for living in groups. In order for animals to live together in groups, they must be able to communicate with each other. Animal communication, like most other animal behaviors, increases fitness. Fitness is the ability to survive and have offspring. Communication increases fitness by helping animals find food, defend themselves from predators, mate, and care for offspring.

Communication

What does the word *communication* make you think of? Talking on a cell phone? Texting? Writing? Those are just a few of the ways that human beings communicate. Most other animals also communicate. **Communication** is any way that animals share information, and they do this in many different ways.

Ways That Animals Communicate

Some animals communicate with sound. Most birds communicate this way. Birds use different calls to warn other birds of danger or to tell them to flock together. Many other

animals also use sound to communicate. For example, monkeys use warning cries to tell other monkeys in their troop that a predator is near. Frogs croak to attract female frogs as mates. Gibbons use calls to tell other gibbons to stay away from their area.

Another way some animals communicate is with sight. By moving in certain ways or "making faces," they show other animals what they mean. Most primates communicate in this way. For example, a male chimpanzee may raise his arms and stare at another male chimpanzee. This warns the other chimpanzee to keep his distance. The chimpanzee in **Figure** 15.20 may look like he is smiling. However, he is really showing fear. He is communicating to other chimpanzees that he will not challenge them. Look at the peacock in **Figure** 15.21. Why is he raising his beautiful tail feathers? He is also communicating. He is showing females of his species that he would be a good mate.

All of the animals pictured here are busy doing something important. Read about what each animal is doing then think about why the animal is behaving that way. These are just a few of the many ways that animals behave.

Figure 15.20: This chimpanzee is communicating with his face. His expression is called a "fear grin." It tells other chimpanzees that he is not a threat. (29)

Some animals communicate with scent. They secrete chemicals that other animals of their species can smell or detect in some other way. Ants secrete many different chemicals. Other ants detect the chemicals with their antennae. This explains how ants are able to work together. The different chemicals that ants secrete have different meanings. Some of the chemicals signal all the ants in a group to come together. Other chemicals warn of danger. Still other chemicals mark trails to food sources. When an ant finds food, it marks the trail

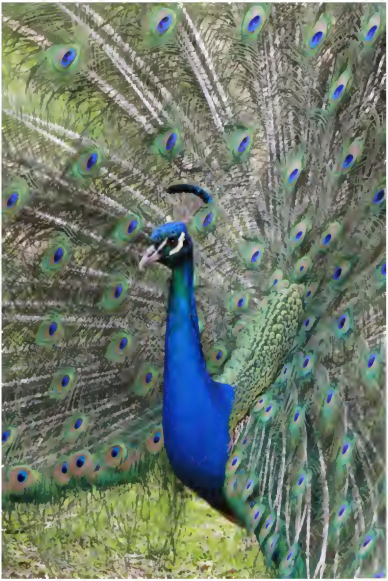

Figure 15.21: This peacock is using his tail feathers to communicate. What is he “saying”? (3)

back to the nest by secreting a chemical on the ground. Other ants follow the chemical trail to the food.

Many other animals also use chemicals to communicate. You have probably seen male dogs raise their leg to urinate on a fire hydrant or other object. Did you know that the dogs were communicating? They were marking their area with a chemical in their urine. Other dogs can smell the chemical. The scent of the chemical tells other dogs to stay away.

Human Communication

Like other animals, humans communicate with one another. They mainly use sound and sight to share information. The most important way that humans communicate is with language. **Language** is the use of symbols to communicate. In human languages, the symbols are words. They stand for many different things. Words stand for things, people, actions, feelings, or ideas. Think of several common words. What does each word stand for?

Another important way that humans communicate is with facial expressions. Look at the faces of the young children in **Figure** 15.22. Can you tell from their faces what the children are feeling? Humans also use gestures to communicate. What are people communicating when they shrug their shoulders? When they shake their head? These are just a few examples of the ways that humans share information without using words.

Social Behavior

Why is animal communication important? Without it, animals would not be able to live together in groups. Animals that live in groups with other members of their species are called **social animals**. Social animals include many species of insects, birds, and mammals. Specific examples of social animals are ants, bees, crows, wolves, and humans. To live together with one another, these animals must be able to share information.

Highly Social Animals

Some species of animals are very social. In these species, members of the group depend completely on one another. Different animals within the group have different jobs. Therefore, group members must work together for the good of all. Most species of ants and bees are highly social animals.

Ants, like those in **Figure** 15.23, live together in large groups called colonies. A colony may have millions of ants. All of the ants in the colony work together as a single unit. Each ant has a specific job. Most of the ants are workers. Their job is to build and repair the colony's nest. Worker ants also leave the nest to find food for themselves and other colony members. The workers care for the young, as well. Other ants in the colony are soldiers. They defend

Figure 15.22: What does this girl's face say about how she is feeling? (18)

the colony against predators. Each colony also has a queen. Her only job is to lay eggs. She may lay millions of eggs each month. A few ants in the colony are called drones. They are the only male ants in the colony. Their job is to mate with the queen.

Figure 15.23: The ants in this picture belong to the same colony. They have left the colony's nest to search for food. (21)

Honeybees and bumblebees also live in colonies. A colony of honeybees is shown in **Figure** 15.24. Each bee in the colony has a particular job. Most of the bees are workers. Young worker bees clean the colony's hive and feed the young. Older worker bees build the waxy honey comb or guard the hive. The oldest workers leave the hive to find food. Each colony usually has one queen that lays eggs. The colony also has a small number of male drones. They mate with the queen.

Cooperation

Ants, bees, and other social animals must cooperate. **Cooperation** means working together with others. Members of the group may cooperate by sharing food. They may also cooperate by defending each other. Look at the ants in **Figure** 15.25. They show clearly why cooperation is important. A single ant would not be able to carry this large insect back to the nest to feed the other ants. With cooperation, the job is easy.

Animals in many other species cooperate. For example, lions live in groups called prides. A lion pride is shown in **Figure** 15.26. All the lions in the pride cooperate. Male lions work together to defend the other lions in the pride. Female lions work together to hunt. Then they share the meat with other pride members.

Meerkats are small mammals that live in Africa. They also live in groups and cooperate with one another. For example, young female meerkats act as babysitters. They take care

Figure 15.24: All the honeybees in this colony work together. Each bee has a certain job to perform. The bees are gathered together to fly to a new home. How do you think they knew it was time to gather together? (26)

Figure 15.25: These ants are cooperating. By working together, they are able to move this much larger insect prey back to their nest. At the nest, they will share the insect with other ants that do not leave the nest. (6)

Figure 15.26: Members of this lion pride work together. Males cooperate by defending the pride. Females cooperate by hunting and sharing the food. (13)

of the baby meerkats while their parents are away looking for food.

Mating Behavior

Some of the most important animal behaviors involve mating. **Mating** is the pairing of an adult male and female to produce young. Adults that are most successful at attracting a mate are most likely to have offspring. Traits that help animals attract a mate and have offspring increase their fitness. If the traits are controlled by genes, they will become more common in the species through natural selection.

Courtship Behaviors

In many species, females choose the male they will mate with. For their part, males try to be chosen as mates. They show females that they would be a better mate than the other males. To be chosen as a mate, males may perform **courtship behaviors**. These are special behaviors that help attract a mate. Male courtship behaviors get the attention of females and show off a male's traits. Different species have different courtship behaviors. Remember the peacock raising his tail feathers in Figure 1b? This is an example of courtship behavior. The peacock is trying to impress females of his species with his beautiful feathers.

Another example of courtship behavior in birds is shown in **Figure** 15.27. This bird is called a blue-footed booby. He is doing a dance to attract a female for mating. During the dance, he spreads out his wings and stamps his feet on the ground. You can watch a video of a blue-footed booby doing his courtship dance at: http://www.travelpod.com/travel-photo/harryandnorah/the_other_way/1199840760/blue-footed-booby-courting-dance.avi/tpod.html.

Courtship behaviors occur in many other species. For example, males in some species of whales have special mating songs to attract females as mates. Frogs croak for the same reason. Male deer clash antlers to court females. Male jumping spiders jump from side to side to attract mates. To see a video of a jumping spider courting a mate, go to: http://video.aol.com/video-detail/courtship-and-mating-of-the-jumping-spider-lyssomanes-viridis-araneae-2837652909.

Courtship behaviors are one type of display behavior. A **display behavior** is a fixed set of actions that carries a specific message. Although many display behaviors are used to attract mates, some display behaviors have other purposes. For example, display behaviors may be used to warn other animals to stay away, as you will read below.

Figure 15.27: This blue-footed booby is a species of sea bird. The male pictured here is doing a courtship "dance." He is trying to attract a female for mating. (12)

Caring for the Young

In most species of birds and mammals, one or both parents care for their offspring. Caring for the young may include making a nest or other shelter. It may also include feeding the young and protecting them from predators. Caring for offspring increases their chances of surviving. When parents help their young survive, they increase their own fitness.

Birds called killdeers have an interesting way to protect their chicks. When a predator gets too close to her nest, a mother killdeer pretends to have a broken wing. The mother walks away from the nest holding her wing as though it is injured. This is what the killdeer in **Figure** 15.28 is doing. The predator thinks she is injured and will be easy prey. The mother leads the predator away from the nest and then flies away.

In most species of mammals, parents also teach their offspring important skills. For example, meerkat parents teach their pups how to eat scorpions without being stung. A scorpion sting can be deadly, so this is a very important skill. Teaching the young important skills makes it more likely that they will survive.

Defending Territory

Some species of animals are territorial. This means that they defend their area. The area they defend usually contains their nest and enough food for themselves and their offspring. A species is more likely to be territorial if there is not very much food in their area.

Figure 15.28: This mother killdeer is pretending she has a broken wing. She is trying to attract a predator's attention in order to protect her chicks. This behavior puts her at risk of harm. How can it increase her fitness? (30)

Animals generally do not defend their territory by fighting. Instead, they are more likely to use display behavior. The behavior tells other animals to stay away. It gets the message across without the need for fighting. Display behavior is generally safer and uses less energy than fighting.

Male gorillas use display behavior to defend their territory. They pound on their chests and thump the ground with their hands to warn other male gorillas to keep away from their area. The robin in **Figure** 15.29 is also using display behavior to defend his territory. He is displaying his red breast to warn other robins to stay away.

Some animals deposit chemicals to mark the boundary of their territory. This is why dogs urinate on fire hydrants and other objects. Cats may also mark their territory by depositing chemicals. They have scent glands in their face. They deposit chemicals by rubbing their face against objects.

Cycles of Behavior

Many animal behaviors change in a regular way. They go through cycles. Some cycles of behavior repeat each year. Other cycles of behavior repeat every day.

Yearly Cycles

An example of a behavior with a yearly cycle is **hibernation**. Hibernation is a state in which an animal's body processes are slower than usual and its body temperature falls. An

Figure 15.29: The red breast of this male robin is easy to see. The robin displays his bright red chest to defend his territory. It warns other robins to keep out of his area. (19)

animal uses less energy than usual during hibernation. This helps the animal survive during a time of year when food is scarce. Hibernation may last for weeks or months. Animals that hibernate include species of bats, squirrels, and snakes.

Most people think that bears hibernate. In fact, bears do not go into true hibernation. In the winter, they go into a deep sleep. However, their body processes do not slow down very much. Their body temperature also remains about the same as usual. Bears can be awakened easily from their winter sleep.

Another example of a behavior with a yearly cycle is **migration**. Migration is the movement of animals from one place to another. Migration is an innate behavior that is triggered by changes in the environment. For example, animals may migrate when the days get shorter in the fall. Migration is most common in birds, fish, and insects. In the Northern Hemisphere, many species of birds, including robins and geese, travel south for the winter. They migrate to areas where it is warmer and where there is more food. They return north in the spring. A flock of migrating geese is shown in **Figure** 15.30.

Figure 15.30: These geese are flying south for the winter. Flocks of geese migrate in V-shaped formations. (9)

Some animals migrate very long distances. The map in **Figure** 15.31 shows the migration route of a species of hawk called Swainson's hawk. About how many kilometers do the hawks travel from start to finish? Are you surprised that birds migrate that far? Some species of birds migrate even farther.

Birds and other migrating animals follow the same routes each year. How do they know where to go? It depends on the species. Some animals follow landmarks, such as rivers or coastlines. Other animals are guided by the position of the sun, the usual direction of the wind, or other clues in the environment.

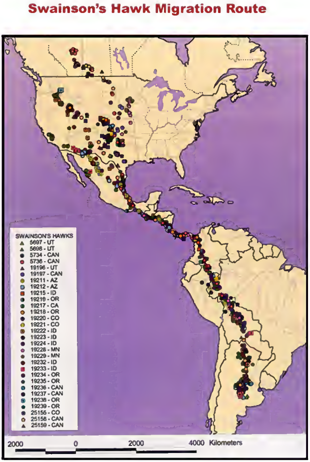

Figure 15.31: The migration route of Swainson's hawk starts in North America and ends in South America. Scientists learned their migration route by attaching tiny tracking devices to the birds. The birds were then tracked by satellite. On the migration south, the hawks travel about 8,000 kilometers from start to finish. (25)

Daily Cycles

Many animal behaviors change at certain times of day, day after day. For example, most animals go to sleep when the sun sets and wake up when the sun rises. Animals that are active during the daytime are called diurnal. Some animals do the opposite. They sleep all day and are active during the night. These animals are called nocturnal. Animals may eat and drink at certain times of day, as well. Humans have daily cycles of behavior, too. Most people start to get sleepy after dark and have a hard time sleeping when it is light outside. Daily cycles of behavior are called **circadian rhythms**.

In many species, including humans, circadian rhythms are controlled by a tiny structure called the **biological clock**. This structure is located in a gland at the base of the brain. The biological clock sends signals to the body. The signals cause regular changes in behavior and body processes. The amount of light entering the eyes controls the biological clock. That's why the clock causes changes that repeat every 24 hours.

Lesson Summary

- Communication is any way that animals share information.
- Social animals live together in groups and cooperate with one another.
- Some of the most important animal behaviors involve attracting mates and caring for offspring.
- Some animals defend the area where they live from other animals.
- Many animal behaviors occur in cycles that repeat yearly or daily.

Review Questions

1. List two ways that animals communicate.
2. Describe how ants in a colony cooperate.
3. What is courtship behavior?
4. Why do male dogs urinate on fire hydrants and other objects?
5. Give an example of a circadian rhythm.
6. How do ants use chemicals to communicate?
7. Explain how courtship behaviors could evolve.
8. How do adult animals increase their own fitness by teaching skills to their young?
9. What is the advantage of animals using display behavior instead of fighting to defend their territory?
10. What is migration, and why do animals migrate?

Further Reading / Supplemental Links

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Vocabulary

biological clock Tiny structure in the brain that controls circadian rhythms.

circadian rhythms An organism's daily cycles of behavior.

communication Any way that animals share information.

cooperation Working together with others.

courtship behaviors Special behaviors that help attract a mate.

display behavior Fixed set of actions that carries a specific message.

hibernation State in which an animal's body processes are slower than usual.

language Use of symbols (or sounds) to communicate.

mating Pairing of an adult male and female to produce young.

migration Movement of animals from one place to another; often seasonal.

social animals Animals that live in groups with other members of their species.

Points to Consider

- The biological clock located just below the human brain controls behaviors such as the sleep-wake cycle.
- The brain is part of the nervous system. What other body system are found in humans?
- Which body system includes the bones? Which system includes the muscles? What do bones and muscles do?

Image Sources

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Chapter 16

Skin, Bones, and Muscles

16.1 Lesson 16.1: Organization of Your Body

Lesson Objectives

- List the levels of organization in the human body.
- Identify the four types of tissues that make up the body.
- Identify 12 organ systems.
- Describe how organs and organ systems work together to maintain homeostasis.

Check Your Understanding

- What is a cell?
- What are some of the differences between a prokaryotic cell and an eukaryotic cell?
- What are some of the basic functions of animal cells?

Introduction

The men in **Figure** 16.1 have just jumped into freezing icy water. They are having fun, but imagine how cold they must feel! One minute their bodies were wrapped in warm clothes, the next, they were dunked in freezing water. Their bodies are now working hard to adapt to the sudden great change in temperature. The ability of the body to maintain a stable internal environment in the response to change is called *homeostasis*. **Homeostasis** allows your body to adapt to change, such as jumping into cold water, running in hot weather, or not getting enough food when you are hungry. Homeostasis is an important characteristic of living things.

Figure 16.1: The bodies of these swimmers are working hard to maintain homeostasis while they are in the icy pool water. Otherwise, their life processes would stop working as soon as they got into the water. (5)

Cells, Tissues, and Organs

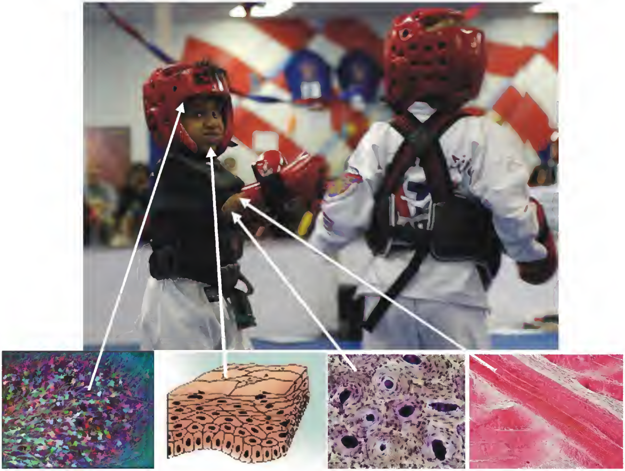
Cells are the most basic units of life in your body. They must do many jobs to maintain homeostasis, but each cell does not have to do every job. Cells have specific jobs to maintain homeostasis. For example, nerve cells move electrical messages around the body, and white blood cells patrol the body and attack invading bacteria. There are many additional different types of cells. Other cells include red blood cells, skin cells, cells that line the inside of your stomach, and muscle cells.

Groups of Cells Form Tissues

Cells are grouped together to carry out specific functions. A group of cells that work together is called a tissue. Your body has four main types of tissues, as do the bodies of other animals. These tissues make up all structures and contents of your body. An example of each tissue type is shown in **Figure** 16.2.

- **Epithelial tissue** is made up of layers of tightly packed cells that line the surfaces of the body. Examples of epithelial tissue include the skin, the lining of the mouth and nose, and the lining of the digestive system.

- **Connective tissue** is made up of many different types of cells that are all involved in structure and support of the body. Examples include blood, cartilage, and bone.



Nervous (brain) Epithelial (skin) Connective (bone) Muscle (skeletal muscle)

Figure 16.2: Your body has four main types of tissue; nervous tissue, epithelial tissue, connective tissue, and muscle tissue. They are found throughout your body. (17)

- **Muscle tissue** is made up of cells that have filaments that move past each other and change the size of the cell. There are three types of muscle tissue: smooth muscle, skeletal muscle, and cardiac muscle.

- **Nervous tissue** is made up of the nerve cells that together form the nervous system. Nervous tissue is found in nerves, the spinal cord, and the brain.

Groups of Tissues Form Organs

A single tissue alone cannot do all the jobs that are needed to keep you alive and healthy. Two or more tissues working together can do a lot more. An **organ** is a structure made of two or more tissues that work together. The heart, shown in **Figure** 16.3, is made up of four types of tissues.

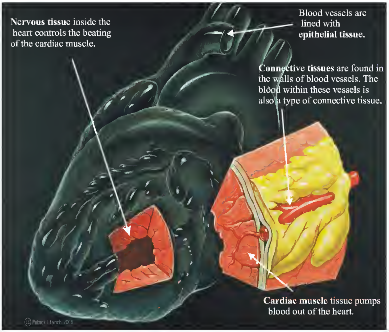


Figure 16.3: The four different tissue types work together in the heart as they do in the other organs. (27)

Groups of Organs Form Organ

Systems Your heart pumps blood around your body. However, your heart needs to be able to get blood to and from every cell in your body in order to do its job. So, your heart is connected to blood vessels such as veins and arteries. Organs that work together form an

organ system. Together, your heart, blood, and blood vessels form your *cardiovascular system.*

Organ Systems Work Together

Your body's 12 organ systems are shown in **Table** 16.1. Your organ systems do not work alone in your body. They must all be able to work together to maintain homeostasis. For example, when the men in **Figure** 16.1 jumped into the cold water, their integumentary systems (skin, hair, nails), cardiovascular systems, muscular systems, and nervous systems work quickly together to ensure the icy-cold water did not cause harm to their bodies. The nervous system sent nerve messages from the skin to tell the cardiovascular system to reduce the blood flow to the skin. Blood flow is then increased to the internal organs and large muscles to help keep them warm and supply them with oxygen. The nervous system also sent messages to the respiratory system to breathe faster. This allows for more oxygen to be delivered by the blood to the muscular system which is shivering and moving about to keep the body warm. **Feedback loops** in the nervous and endocrine systems regulate conditions in the body. A feedback loop is a path that leads from the initial generation of the signal to the subsequent modification of the initial event. For example, the men that jumped into the cold water do not need to continue to breathe faster and faster. Feedback loops return the respiratory system to "normal." One of the most important functions of organ systems is to provide cells with oxygen and nutrients and removes toxic waste products such as carbon dioxide. A number of organ systems, including the cardiovascular and respiratory systems, work together to do this.

Table 16.1: **Major Organ Systems of the Human Body**

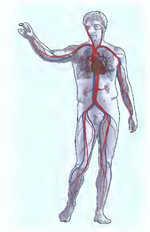
Organ System	Major Tissues and Organs	Function	Example
Cardiovascular	Heart; blood vessels; blood	Transports oxygen, hormones and nutrients to the body cells, and wastes and carbon dioxide away from cells	

Table 16.1: (continued)

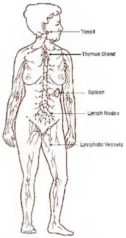
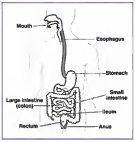
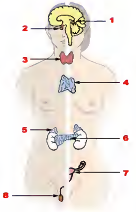
Organ System	Major Tissues and Organs	Function	Example
Lymphatic	Lymph nodes; lymph vessels	Defense against infection and disease, transfer of lymph between tissues and the blood stream	
Digestive	Esophagus; stomach; small intestine; large intestine	Processing of foods and absorption of nutrients, minerals, vitamins, and water	
Endocrine	Pituitary gland, hypothalamus; adrenal glands; Islet of Langerhans; ovaries; testes	Communication within the body with hormones; directing long-term change over other organ systems to maintain homeostasis	

Table 16.1: (continued)

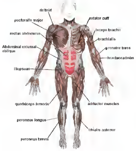
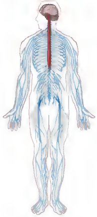
Organ System	Major Tissues and Organs	Function	Example
Integumentary	Skin, hair, nails	Protection from injury and fluid loss; physical defense against infection by microorganisms; temperature control	
Muscular	Cardiac (heart) muscle; skeletal muscle; smooth muscle; tendons	Movement, support, heat production	
Nervous	Brain, spinal cord; nerves	Collecting, transferring and processing information; directing short-term change over other organ systems in order to maintain homeostasis	
Reproductive	Female: uterus; vagina; fallopian tubes; ovaries Male: penis; testes; seminal vesicles	Production of gametes (sex cells) and sex hormones; production of offspring	

Table 16.1: (continued)

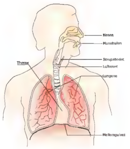
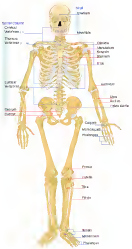
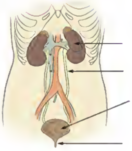
Organ System	Major Tissues and Organs	Function	Example
Respiratory	Trachea, larynx, pharynx, lungs	Delivery of air to sites where gas exchange can occur between the blood and cells (around body) or blood and air (lungs)	
Skeletal	Bones, cartilage; ligaments	Support and protection of soft tissues of body; movement at joints; production of blood cells; mineral storage	
Urinary	Kidneys; urinary bladder	Removal of excess water, salts, and waste products from blood and body; control of pH; regulates water and electrolyte balance	

Table 16.1: (continued)

Organ System	Major Tissues and Organs	Function	Example
Immune	Skin; bone marrow; spleen; white blood cells	Defending against microbial pathogens (disease-causing agents) and other diseases	

Figures in table above: Each body system works together to maintain homeostasis of other systems and of the entire organism. No system of the body works alone, and your well-being depends upon the well-being of all the body systems. A problem in one system usually affects other body systems.

Homeostasis and Feedback Regulation

Homeostasis refers to stability, balance, or equilibrium within a cell or the body. It is an organism's ability to keep a constant internal environment. Homeostasis is an important characteristic of living things. Keeping a stable internal environment requires constant adjustments as conditions change inside and outside the cell. Because the internal and external environments of a cell are constantly changing, adjustments must be made continuously to stay at or near the set point (the normal level or range).

The endocrine system plays an important role in homeostasis because **hormones**, which are the messengers of the endocrine system, regulate the activity of body cells. The release of hormones into the blood is controlled by a stimulus, or signal. For example, the stimulus either causes an increase or a decrease in the amount of hormone released. Then, the response to the signal changes the internal conditions and may itself become a new stimulus. This self-adjusting mechanism is called feedback regulation.

Feedback regulation occurs when the response to a stimulus has an effect of some kind on the original stimulus. The type of response determines what the feedback is called. **Negative feedback** occurs when the response to a stimulus reduces the original stimulus. **Positive feedback** occurs when the response to a stimulus increases the original stimulus.

Thermoregulation: A Negative Feedback Loop

Negative feedback is the most common feedback loop in the body. The system acts to reverse the direction of change, keeping things constant. For instance, when the concentration of carbon dioxide in the human body increases, the lungs are signaled to increase their activity

and exhale more carbon dioxide, so your breathing rate increases. **Thermoregulation** is another example of negative feedback. When body temperature rises, receptors in the skin and the brain sense the temperature change. The temperature change (signal) triggers a command from the brain. This command, causes a response (the skin makes sweat and blood vessels near the skin surface dilate), which helps decrease body temperature. **Figure** 16.4 shows how the response to a stimulus reduces the original stimulus in another of the body's negative feedback mechanisms.

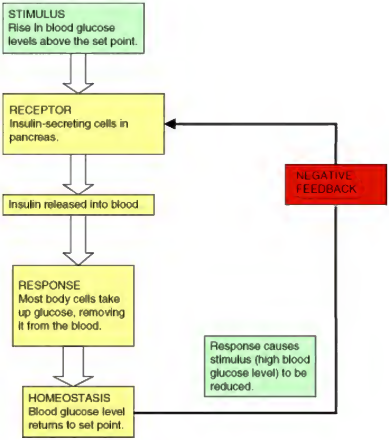


Figure 16.4: Control of blood glucose level is an example of negative feedback. Blood glucose concentration rises after a meal (the stimulus). The hormone insulin is released by the pancreas, and it speeds up the transport of glucose from the blood and into selected tissues (the response). Blood glucose concentrations then decrease, which then decreases the original stimulus. The secretion of insulin into the blood is then decreased. (24)

Positive feedback is less common in biological systems. Positive feedback acts to speed up the direction of change. An example of positive feedback is lactation (milk production). As the baby drinks its mother's milk, nerve messages from the mammary glands cause a hormone, prolactin, to be released. The more the baby suckles, the more prolactin is released, which stimulates further milk production.

Not many feedback mechanisms in the body are based on positive feedback. Positive feedback speeds up the direction of change, which leads to increasing hormone concentration, a state that moves further away from homeostasis.

Lesson Summary

- The levels of organization in the human body include: cells, tissues, organs, and organ systems. A tissue is a group of cells that work together. An organ is made of two or more tissues that work together. Organs that work together make up organ systems.
- There are four tissue types in the body: epithelial tissue, connective tissue, muscle tissue, and nervous tissue. There are 12 major organ systems in the body. Organs and organ systems work together to maintain homeostasis.

Review Questions

1. What is homeostasis?
2. What are the four levels of organization in an organism?
3. What is the difference between a tissue and an organ?
4. List the four types of tissues that make up the human body.
5. A classmate says that all four tissue types are never found together in an organ.
6. Why do you think an organ is able to do many more jobs than a single tissue can?
7. Identify the organ system to which the following organs belong: skin, stomach, brain, lungs, and heart.
8. Give an example of how two organ systems work together to maintain homeostasis.

Further Reading / Supplemental Links

- http://en.wikipedia.org/wiki/Tissue_%28biology%29

Vocabulary

cardiovascular system The body system that include the heart, blood, and blood vessels.

connective tissue Tissue that is made up of different types of cells that are involved in structure and support of the body; includes blood, bone, and cartilage.

epithelial tissue A tissue that is composed of layers of tightly packed cells that line the surfaces of the body; examples of epithelial tissue include the skin, the lining of the mouth and nose, and the lining of the digestive system.

homeostasis The ability of the body to maintain a stable internal environment in the response to external changes.

muscular tissue Tissue that is composed of cells that have filaments that move past each other and change the size of the cell. There are three types of muscle tissue: smooth muscle, skeletal muscle, and cardiac muscle.

nervous tissue Composed of nerve cells and related cells.

organ A structure made of two or more tissues that work together.

organ system A group of organs that work together.

tissue SA group of cells that work together for a common purpose.

Points to Consider

- What are the levels of organization of the integumentary system?
- What other body systems does the integumentary system work with to maintain homeostasis?

16.2 Lesson 16.2: Integumentary System

Lesson Objectives

- List the functions of skin.
- Describe the structure of skin.
- Describe the structure of hair and nails.
- Identify two types of skin problems.
- Describe two ways to take care of your skin.

Check Your Understanding

- What is homeostasis?
- What is epithelial tissue?

Introduction

Did you know that you see the largest organ in your body every day? You wash it, dry it, cover it up to stay warm or uncover it to cool off. In fact, you see it so often it is easy to forget the important role your skin plays in keeping you healthy. Your skin is part of your **integumentary system** (**Figure** 16.5), which is the outer covering of your body. The integumentary system is made up of your skin, hair, and nails.

Figure 16.5: Skin acts as a barrier that stops water and other things, like soap and dirt, from getting into your body. (6)

Your Skin and Homeostasis

Your integumentary system has many roles in homeostasis, including protection, the sense of touch, and regulating body temperature. Keeping water out of the body is an important role for your integumentary system. If this were not so, the man in Figure 1 would not be able to bathe. All of your body systems work together to maintain stable internal conditions. Each of the parts that make up your integumantary system has a special role in maintaining homeostasis which we will explore a little later.

Functions of Skin

Your skin covers the entire outside of your body. Your skin is your body's largest organ yet it is only about 2 mm thick. It has many important functions, some of these include:

- It acts as a barrier. It keeps organisms that could harm the body out. It stops water from leaving the body, and stops water from getting into the body.
- It helps regulate body temperature. It does this by making sweat, a watery substance which cools the body when it evaporates.
- It helps you to gather information about your environment. Special nerve endings in your skin sense heat, pressure, cold and pain.
- It helps the body get rid of some types of waste, which are removed in sweat.
- It acts as a sun block. A chemical called *melanin* is made by certain skin cells when they are exposed to sunlight. Melanin blocks sun light from getting to deeper layers of skin cells, which are easily damaged by sun light.

Structure of Skin

Your skin is always exposed to your external environment so it gets cut, scratched, and worn down. You also naturally shed many skin cells every day. Your body replaces damaged or missing skin cells by growing more of them. The layer of skin that you can see is actually dead. The dead cells are filled with a tough, waterproof protein called **keratin**. As the dead cells are shed or are removed from the upper layer, they are replaced by the skin cells below them.

As you can see in **Figure** 16.6, two different layers make up the skin. These layers are the **epidermis** and the **dermis**. A fatty layer, called **subcutaneous tissue**, lies under the dermis, but it is not part of your skin. The layers that make up your skin are shown in **Figure** 16.6.

The color, thickness and texture of skin vary over the body. There are two general types of skin; thin and hairy, which is the most common type on the body, and thick and hairless, which is found on parts of the body that experience a lot of friction, such as the palms of the hands or the soles of the feet.

Epidermis

Epidermis is the outermost layer of the skin. It forms the waterproof, protective wrap over the body's surface and is made up of many layers of *epithelial* cells (discussed in lesson 1). The epidermis is divided into several layers where epithelial cells are formed by mitosis in the lowest layer. The epithelial cells move up through the layers of the epidermis, changing shape and composition as they divide and become filled with keratin. The skin cells at the

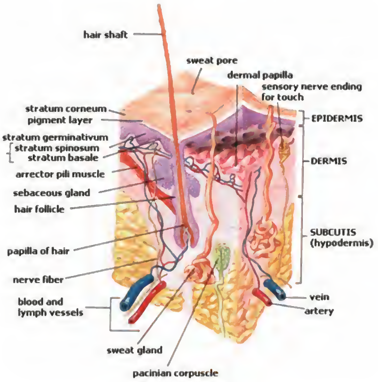


Figure 16.6: Skin is made up of two layers, the epidermis on top, and the dermis below. The tissue below the dermis is called the hypodermis, but it is not part of the skin. (20)

surface of the epidermis form a thin layer of flattened, dead cells. Although the top layer of epidermis is only about as thick as a sheet of paper, it is made up of 25 to 30 layers of cells.

The epidermis also contains cells that produce *melanin*. **Melanin** is the brownish pigment that gives skin and hair their color. Melanin-producing cells are found in the bottom layer of the epidermis. The epidermis does not have any blood vessels. The lower part of the epidermis is fed by diffusion from the blood vessels of the dermis.

Dermis

The **dermis** is the layer of skin directly under the epidermis. It is made of a tough connective tissue that contains the protein *collagen*. **Collagen** is a long, fiber-like protein that is very strong. The dermis is tightly connected to the epidermis by a membrane made of collagen fibers. As you can see in **Figure** 16.6, the dermis contains the hair follicles, sweat glands, oil glands, and blood vessels. It also holds many nerve endings that give you your sense of touch, pressure, heat, and pain. Tiny muscles in the dermis pull on hair follicles which cause hair to stand up. This can happen when you are cold or afraid. The resulting little "bumps" in the skin are commonly called *goosebumps*, shown in **Figure** 16.7.

Figure 16.7: Goose bumps are caused by tiny muscles in the dermis that pull on hair follicles, which causes the hairs to stand up straight. (23)

Oil Glands and Sweat Glands

Glands and follicles open out into the epidermis, but they start in the dermis. **Oil glands** secrete an oily substance, called *sebum*, into the hair follicle. An oil gland is shown in **Figure** 16.6. Sebum "waterproofs" hair and the skin surface to prevent them from drying out. It can also stop the growth of bacteria on the skin. Sebum is the cause of the oily appearance of skin and hair. It is odorless, but the breakdown of sebum by bacteria can cause odors. If an oil gland becomes plugged and infected, it develops into a pimple, also called *acne*.

Sweat glands open to the skin surface through skin pores. They are found all over the body. Evaporation of sweat from the skin surface helps to lower the skin temperature, which in turn helps to control body temperature. The skin also releases excess water, salts, and other wastes in sweat. A sweat gland is shown in **Figure** 16.6.

Nails and Hair

Nails and hair are made of the same types of cells that make up skin. Hair and nails contain the tough protein *keratin*. Both hair and nails are important parts of your integumentary system.

Fingernails and toenails both grow from nail beds. A nailbed is thickened to form a lunula (or little moon), which you can see in **Figure** 16.8. Cells forming the nail bed are linked together to form the nail. As the nail grows more cells are added at the nail bed. Older cells get pushed away from the nail bed and the nail grows longer. There are no nerve endings in the nail, which is a good thing, otherwise cutting you nails would hurt a lot!

Nails act as protective plates over the fingertips and toes. Fingernails also help in sensing the environment. The area under your nail has many nerve endings, which allow you to receive more information about objects you touch. Nails are made up of many different parts, as shown in **Figure** 16.8.

Hair sticks out from the epidermis, although it grows from hair follicles deep in the dermis, as shown in **Figure** 16.9. Hair is made of keratin, the same protein that makes up skin and nails. Hair grows from inside the hair follicle. New cells grow in the bottom part of the hair, called the *bulb*. Older cells get pushed up, and the hair grows longer. Similar to nails and skin, the cells that make up the hair strand are dead and filled with keratin. Hair color is the result of different types of melanin in the hair cells. In general, the more melanin in the cells, the darker the hair color; the less melanin, the lighter the hair color.

Hair helps to keep the body warm. When you feel cold, your skin gets a little bumpy. These bumps are caused by tiny muscles that pull on the hair, causing the hair to stick out. The erect hairs help to trap a thin layer of air that is warmed by body heat. In mammals that have much more hair than humans, the hair traps a layer of warm air near the skin and acts like warm blanket. Hair also protects the skin from ultraviolet radiation (UV radiation) from the sun. Hair also acts as a filter. Nose hair helps to trap particles in the air that may

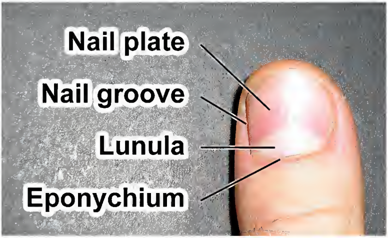


Figure 16.8: The structure of fingernails is similar to toenails. The *free edge* is the part of the nail that extends past the finger, beyond the nail plate. The *nail plate* is what we think of when we say "nail," the hard portion made of the tough protein keratin. The *lunula* is the crescent shaped whitish area of the nail bed. The *cuticle* is the fold of skin at the end of the nail. (16)

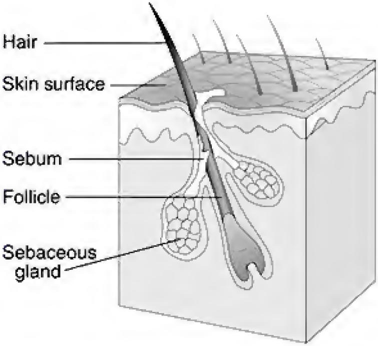


Figure 16.9: Hair, hair follicle, and oil glands. The oil, called sebum, helps to prevent water loss from the skin. (14)

otherwise travel to the lungs. Eyelashes shield eyes from dust and sunlight. Eyebrows stop salty sweat and rain from flowing into the eye.

Keeping Skin Healthy

Some sunlight is good for health. Vitamin D is made in the skin when it is exposed to sunlight. But, getting too much sun can be unhealthy. A **sunburn** is a burn to the skin that is caused by overexposure to UV radiation from the sun's rays or tanning beds. Light-skinned people, like the girl in **Figure** 16.10, get sunburned more quickly than people with darker skin do. This is because melanin in the skin acts as a natural sunblock that helps to protect the body from UV radiation. When exposed to UV radiation, certain skin cells make melanin, which causes skin to tan. Children and teens who have gotten sunburned are at a greater risk of developing skin cancer later in life than children and teens who have not.

Long-term exposure to UV radiation is the leading cause of skin cancer. About 90 percent of skin cancers are linked to sun exposure. UV radiation damages the genetic material of skin cells. This damage can cause the skin cells to grow out of control and form a tumor. Some of these tumors are very difficult to cure. For this reason you should always wear sunscreen with a high sun protection factor (SPF), a hat, and clothing when out in the sun. As people age, their skin gets wrinkled. Wrinkles are caused mainly by UV radiation and by the loosening of the connective tissue in the dermis due to age.

Figure 16.10: Sunburn is caused by overexposure to UV rays. Getting sunburned as a child or a teen, especially sunburn that causes blistering, increases the risk of developing skin cancer later in life. (29)

Because some types of skin cancer are easy to cure, the dangers of too much sunlight are not always taken seriously by people. It is important to remember that a more serious form of skin cancer, called **melanoma**, is also associated with long-term sun exposure.

Melanomas are difficult to treat, and potentially deadly tumors. The best way to avoid skin cancer is to cover up when outside in the sun, and to wear sunscreen.

Bathing and Skin Hygiene

During the day, your skin can collect many different things. Sweat, oil, dirt, dust, and dead skin cells can build up on the skin surface. If not washed away, the mix of sweat, oil, dirt, and dead skin cells can encourage the excess growth of bacteria. These bacteria feed on these substances and cause a smell that is commonly called *body odor*. Dirty skin is also more prone to infection. Bathing every day helps to remove dirt, sweat and extra skin cells, and helps to keep your skin clean and healthy.

Acne

Hormones can affect your skin. Certain hormones cause oil glands in the skin to make an oil called *sebum*. When too much sebum is made by oil glands, it can cause the hair follicles to get blocked with dead skin cells. Within these blocked pores bacteria and yeast begin to multiply. In response to the growth of the bacteria and yeast, the skin inflames. This skin inflammation produces the red bumps that are called *acne*. Up to 85% of teenagers get acne. Acne usually goes away by adulthood. Frequent washing can help reduce the amount of sebum and dead skin cells on the skin. But washing cannot prevent the excessive sebum production that leads to acne.

Injury

Your skin can heal itself even after a large cut. Cells that are damaged or cut away are replaced by cells that grow in the bottom layer of the epidermis and the dermis. These new cells will eventually replace the damaged tissues.

When an injury is deep enough through the epidermis into the dermis, bleeding occurs. A blood clot and scab soon forms. After the scab is formed, cells in the base of the epidermis begin to divide by and move to the edges of the scab. A few days after the injury, the edges of the wound are pulled together. If the cut is large enough, the production of new skin cells will not be able to heal the wound. Stitching the edges of the injured skin together can help the skin to repair itself. The person in **Figure** 16.11 had a large cut that needed to be stitched together. When the damaged cells and tissues are replaced, the stitches will be removed.

Lesson Summary

- Skin acts as a barrier that keeps particles and water out of the body.

Figure 16.11: Sewing the edges of a large cut together allows the body to repair the damaged cells and tissues, and heal the tear in the skin. (9)

- The skin helps to cool the body in hot temperatures, and keep the body warm in cool temperatures. It also help you to sense your surroundings.
- Skin is made up of two layers, the epidermis and the dermis. Hair and nails are made of the same type of protein as skin is.
- Nails grow from nail beds and hairs grow from hair follicles in the skin.
- Acne is a skin problem that happens when the skin makes too much sebum.
- Skin cancer can be caused by excess exposure to ultraviolet light from the sun or tanning beds.
- Bathing frequently helps keep the skin clean and healthy.
- Wearing sunblock and a hat when outdoors can help prevent skin cancer.

Review Questions

1. Identify two functions of skin.
2. How does the integumentary system help maintain homeostasis?
3. Describe the structure of skin.
4. Identify the layer of skin from which hair grows.
5. In what way are hairs and nails similar to skin?
6. Name two functions of nails.
7. Name two functions of hair.
8. What type of skin problem happens when the skin makes too much sebum?
9. The World Health Organization recommends that no person younger than 18 years old use a tanning bed. Why do you think using a tanning bed is not recommended?
10. How does washing your skin help to keep you healthy?
11. Why are stitches sometimes needed if a person gets a deep or long cut in their skin?

Further Reading / Supplemental Links

- http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5540a9.htm
- http://www.cdc.gov/Features/SkinCancer
- http://en.wikipedia.org/wiki

Vocabulary

body odor Smell that is produced by the breakdown of sweat by bacteria that live on the skin.

dermis The layer of skin directly under the epidermis; made of a tough connective tissue that contains the protein collagen.

epidermis The outermost layer of the skin; forms the waterproof, protective wrap over the body's surface; made up of many layers of epithelial cells.

integumentary system The outer covering of the body; made up of the skin, hair, and nails.

keratin Tough, waterproof protein that is found in epidermal skin cells, nail, and hair.

melanin The brownish pigment that gives skin and hair their color.

melanocyte Melanin-producing cells; found in the bottom layer of the epidermis.

melanoma Cancer of melanin-containing cells (melanocytes); mostly linked to long-term exposure to UV radiation.

oil gland Skin organ that secretes an oily substance, called sebum, into the hair follicle.

subcutaneous tissue Fatty layer of tissue that lies under the dermis, but is not part of the skin.

sunburn A burn to the skin that is caused by overexposure to UV radiation from the sun's rays or tanning beds.

sweat gland Gland that opens to the skin surface through skin pores; found all over the body; secretes sweat.

Points to Consider

- How might what you eat affect your bones?
- What do you think is the most important function of your skeletal system?

16.3 Lesson 16.3: Skeletal System

Lesson Objectives

- Identify the main tissues and organs of the skeletal system.
- List four functions of the skeletal system.
- Describe three movable joints.
- Identify two nutrients that are important for a healthy skeletal system.
- Describe two skeletal system injuries.

Check Your Understanding

- What is an organ system?
- What is connective tissue?

Introduction

How important is your skeleton? Can you imaging your body without it? You would be a wobbly pile of muscle and internal organs, and you would not be able to move around much. You will learn about these functions in this lesson. Your skeleton is important for many different things. Bones are the main organs of the skeletal system. They are made up of living tissue. If you think you have broken a bone it's important to visit a healthcare professional. A broken bone may not heal properly by itself. A sprain can be bandaged up properly to reduce swelling and discomfort. A doctor or other healthcare professional can also give you advice on how to manage such an injury at home.

Your Skeleton

Humans are vertebrates, which are animals that have a backbone. The sturdy scaffolding of bones and cartilage that is found inside vertebrates is called a **skeleton**. The adult human skeleton has about 206 bones, some of which are named in **Figure** 16.12. The skeletons of babies and children have many more bones and more cartilage than adults have. As a child grows, these "extra" bones grow into each other, and cartilage gradually hardens to become bone tissue.

You may think that bones are dry and lifeless, but they are very much alive. The white, hard bones that you might see in a museum or science book, are only the hard mineral remains of the bone tissue. Living bones are full of life. They contain many different types of tissues.

Cartilage is found at the end of bones and is made of tough protein fibers called *collagen*. Cartilage creates smooth surfaces for the movement of bones that are next to each other, like the bones of the knee. **Ligaments** are made of tough protein fibers and connect bones to each other. Your bones, cartilage, and ligaments make up your **skeletal system**.

Functions of Bones

Your skeletal system gives shape and form to your body, but it is also important in other homeostatic functions. The main functions of the skeletal system are:

- **Support** The skeleton supports the body against the pull of gravity. The large bones of the lower limbs support the trunk when standing.

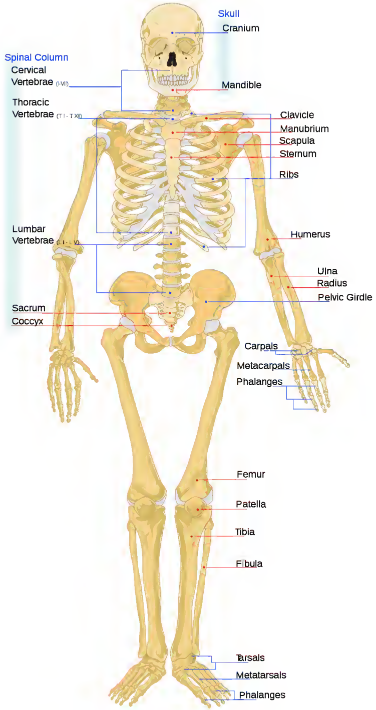


Figure 16.12: The skeletal system is made up of bones, cartilage, and ligaments. The skeletal system has many important functions in your body. (3)

- **Protection** The skeleton provides a framework that supports and protects the soft organs of the body. For example, the skull surrounds the brain to protect it from injury. The bones of the rib cage help protect the heart and lungs.
- **Movement** Bones work together with muscles as simple mechanical lever systems to move the body.
- **Making Blood Cells** Blood cells are made mostly inside certain types of bones.
- **Storage** Bones store calcium. They contain more calcium than any other organ does. Calcium is released by the bones when blood levels of calcium drop too low. The mineral phosphorus is also stored in bones.

Structure of Bones

Bones are *organs*. Recall that organs are made up of two or more types of tissues. Bones come in many different shapes and sizes, but they are all made of the same materials. The two main types of bone tissue are *compact bone* and *spongy bone*. **Compact bone** makes up the dense outer layer of bones. **Spongy bone** is lighter and less dense than compact bone, and is found toward the center of the bone. The tough, shiny, white membrane that covers all surfaces of bones is called the *periosteum*.

Many bones also contain a soft connective tissue called **bone marrow**. There are two types of bone marrow: *red marrow* and *yellow marrow*. Red marrow makes red blood cells, platelets, and most of the white blood cells for the body (discussed in the *Diseases and the Body's Defenses* chapter). Yellow marrow makes white blood cells. The bones of newborn babies contain only red marrow. As children get older, their red marrow is replaced by yellow marrow. In adults, red marrow is found mostly in the bones of the skull, the ribs, and pelvic bones. Bone come in four main shapes. They can be *long, short, flat, or irregular*. Identifying a bone as long, short, flat, or irregular is based on the shape of the bone not the size of the bone. For example, both small and large bones can be classified as long bones. The small bones in your fingers and the largest bone in your body, the femur, are long bones. The structure of a long bone is shown in **Figure** 16.13.

How Bones Develop and Grow

Your skeleton began growing very early in your development. After only eight weeks of growth from a fertilized egg, your skeleton was formed by cartilage and other connective tissues. At this point your skeleton was quite bendy and flexible. After a few more weeks of growth, the cells that form hard bone began growing in the cartilage, and your skeleton began to harden. However, not all of the cartilage is replaced by bone. Cartilage remains in many places in your body including your joints, your rib cage, your ears, and the tip of your nose.

A baby is born with zones of cartilage in its bones that allow growth of the bones. These

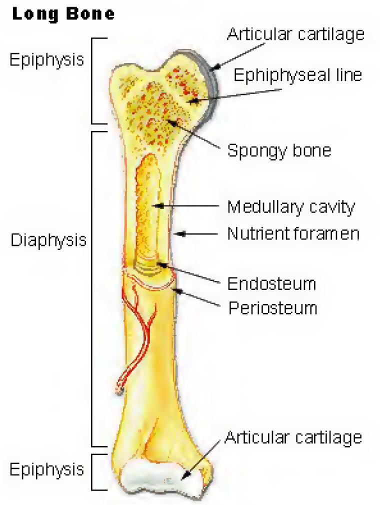


Figure 16.13: Bones are made up of different types of tissues. (12)

areas, called *growth plates*, allow the bones to grow longer as the child grows. When the child reaches an age of about 18 to 25 years, all of the cartilage in the growth plate is replaced by bone. This stops the bone from growing any longer.

Even though bones stop growing in length in early adulthood, they can continue to increase in thickness throughout life. This thickening can be in response to stress from increased muscle activity or to weight-bearing exercise.

Joints and How They Move

A **joint** is a point at which two or more bones meet. There are three types of joints in the body: *fixed, partly movable*, and *movable*. Fixed joints do not allow any bone movement. Many of the joints in your skull are fixed (**Figure** 16.14). Partly movable joints allow only a little movement. Your backbone has partly movable joints between the vertebrae (**Figure** 16.15). Movable joints allow movement and provide mechanical support for the body. Joints are a type of *lever*, which is a rigid object that is used to increase the mechanical force that can be applied to another object. Can openers and scissors are examples of levers. Joints reduce the amount of energy that is spent moving the body around. Just imagine how difficult it would be to walk about if you did not have knees!

Figure 16.14: The skull has fused joints. Fused joints do not allow any movement of the bones, which protects the brain from injury. (8)

Movable Joints

Movable joints are the most mobile joints of all. They are also the most common type of joint in your body. Your fingers, toes, hips, elbows, and knees all have movable joints. The surfaces of bones at movable joints are covered with a smooth layer of cartilage. The space

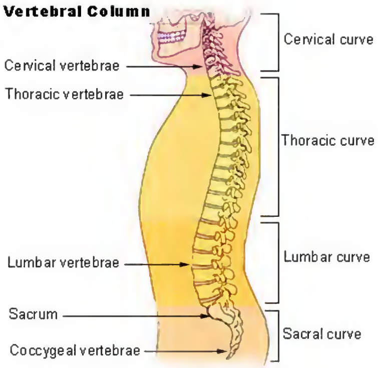


Figure 16.15: The joints between your vertebrae (b) are partially movable. (1)

between the bones in a movable joint is filled with a liquid called *synovial fluid*. Synovial fluid is a thick, stringy fluid that looks a lot like egg white. The fluid lubricates and cushions the bones when they move at the joint. There are many different types of movable joints, and many different examples. Four types of movable joints are shown in **Figures** 16.16, 16.17 and 16.18.

In a **ball and socket joint** the ball-shaped surface of one bone fits into the cup-like shape of another. Examples of a ball and socket joint include the hip, shown in **Figure** 16.16, and the shoulder.

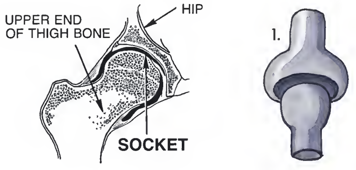


Figure 16.16: Your hip joint is a ball and socket joint. The "ball" end of one bone fits into the "socket" of another bone. These joints can move in many different directions. (13)

In a **hinge joint**, the ends of the bones are shaped in a way that allows motion only in two directions, forward and backward. Examples of hinge joints are the knees and elbows. A knee joint is shown in **Figure** 16.17.

The **pivot joint** is formed by a process that rotates within a ring, the ring being formed partly of bone, and partly of ligament. An example of a pivot joint is the joint between the radius and ulna that allows you to turn the palm of your hand up and down. A pivot joint is shown in **Figure** 16.18.

A **gliding joint** is a joint which allows only gliding movement. The gliding joint allows one bone to slide over the other. The gliding joint in your wrist allows you to flex your wrist. It also allows you to make very small side-to-side motions. There are also gliding joints in your ankles.

Keeping Bones and Joints Healthy

Just like a houseplant depends on you taking good care of it by watering it and giving it plant food, so too does your body depend on you! You can help keep your bones and skeletal system healthy by eating well and getting enough exercise. Weight-bearing exercises help keep bones strong. *Weight-bearing* exercises work against gravity; such activities include basketball, tennis, gymnastics, karate, running, and walking. When the body is exercised

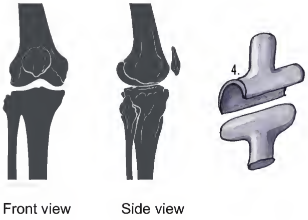


Figure 16.17: The knee joint is a hinge joint. Like a door hinge, a hinge joint allows backward and forward movement. (25)

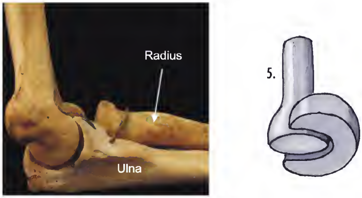


Figure 16.18: Pivot Joint The joint at which the radius and ulna meet is a pivot joint. Movement at this joint allows you to flip your palm over without moving your elbow joint. (28)

regularly by doing a weight-bearing activity, bones respond by adding more bone cells making the bones denser.

Eating Well

Did you know that what you eat now, as a teenager, can affect how healthy your skeletal system will be in 30, 40, and even 50 years from now? Calcium and vitamin D are two of the most important nutrients for a healthy skeletal system. Your bones need calcium to grow properly. If you do not get enough calcium in your diet as a teenager, your bones may become weak and break easily later in life. **Osteoporosis** is a disease in which bones become lighter and more porous than they should be. Light and porous bones are more likely to break, which can cause pain and prevent a person from walking. Being immobile can cause more bone loss which can make the disease worse.

Older women are most likely to develop osteoporosis because it is linked to the decrease in production of sex hormones. However, poor nutrition, especially diets that are low in calcium and vitamin D, increase the risk of osteoporosis in later life. Not doing regular weight-bearing exercises is also linked to having thinner, weaker bones. Two of the easiest ways to prevent osteoporosis is to eat a healthful diet that has the right amount of calcium and vitamin D, and to do weight-bearing exercise day.

Foods that are a good source of calcium include: milk, yogurt, and cheese. Non-dairy sources of calcium include Chinese cabbage, kale, and broccoli. Many fruit juices, fruit drinks, tofu, and cereals have calcium added into them. These foods are also an important source of calcium.

Teenagers are recommended to get 1300 mg of calcium every day. One cup of milk provides about 300 mg of calcium, which about 30% of your daily requirement for calcium. Other sources of calcium are shown in **Figure** 16.19.

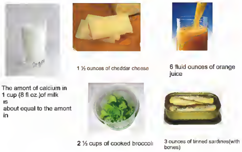


Figure 16.19: There are many different sources of calcium. Getting enough calcium in your daily diet is important for good bone health. How many ounces of cheddar cheese would provide your recommended daily intake of calcium? (2)

Your skin makes vitamin D when exposed to sunlight. The pigment melanin in the skin acts

like a filter that can prevent the skin from making vitamin D. As a result, people with darker skin need more time in the sun than people with lighter skin to make the same amount of vitamin D.

Fish is naturally rich in vitamin D. Vitamin D is added to other foods including milk, soy milk and breakfast cereals. Teenagers are recommended to get 5 micrograms (200 IU/day) of vitamin D every day. A 3 ½ ounce portion of cooked salmon provides 360 IU of vitamin D.

Lack of vitamin D, or *deficiency*, can be caused by two different things: not enough sunlight exposure, and lack of vitamin D in the diet. Vitamin D deficiency results in problems with bone growth and hardening. This leads to bone softening diseases such as rickets in children and osteomalacia in adults. Osteomalacia is a bone disease in which the bones do not harden properly and they can break easily. Rickets is a type of osteomalacia. An X-ray of a child that has rickets is shown in **Figure** 16.20. Lack of vitamin D may also be related to osteoporosis.

Bone Fractures

Even though they are very strong, bones can fracture, or break. Fractures can happen at different places on a bone. They are usually due to excess bending stress on the bone. Bending stress is what causes a pencil to break if you were to bend it too far. Soon after a fracture, the body begins to repair the break. The area becomes swollen and sore. Within a few days bone cells travel to the break site and begin to rebuild the bone. It takes about 2 to 3 months before compact and spongy bone form at the break site.

Sometimes the body needs extra help in repairing a broken bone. In such a case a surgeon will piece a broken bone together with metal pins. Moving the broken pieces together will help keep the bone from moving, and give the body a chance to repair the break. A broken ulna has been repaired with pins in **Figure** 16.21.

Cartilage Injuries

Osteoarthritis is a condition in which the cartilage at the ends of the bones breaks down. The break down of the cartilage leads to pain and stiffness in the joint. Decreased movement of the joint because of the pain may lead to muscles that are attached to the joint to become weaker, and ligaments may become looser. Osteoarthritis is the most common form of arthritis. It has many causes, some of the more common causes include old age, sport injuries to the joint, bone fractures, and overweight and obesity. Total hip replacement is a common treatment for osteoarthritis.

Figure 16.20: Rickets is a softening of the bones in children that may cause fractures and bending of the bones, especially of the legs. The bones have not hardened properly because of lack of vitamin D, and bend under the weight of the body. (7)

Figure 16.21: The upper part of the ulna, at the elbow is broken, as you can see in the X-ray at left. The x-ray at right was taken after a surgeon inserted pins into the joint to keep the two pieces of the ulna together. The two pieces of bone were reattached with metal pins. The line of staples is closing the skin wound. (21)

Ligament Injuries

Recall that a ligament is a short band of tough connective tissue that connects bones together to form a joint. Ligaments can get injured when a joint gets twisted or bends too far. The protein fibers that make up a ligament can get strained or torn, causing swelling and pain. Injuries to ligaments are called **sprains**. Ankle sprains are a common type of sprain. A small ligament in the knee, called the *anterior cruciform ligament* (ACL), is a common site of injury in athletes. Ligament injuries can take a long time to heal. Treatment of the injury includes rest and special exercises that are developed by a physical therapist.

Preventing Injuries

Preventing injuries to your bones and ligaments is easier and much less painful than treating an injury. Wearing the correct safety equipment when doing activities that require safety equipment can help prevent many common injuries. For example, wearing a bicycle helmet can help prevent a skull injury if you fall. Warming up and cooling down properly can help prevent ligament and muscle injuries. Torn ligaments and fractured bones are common sport injuries. Such injuries need to be treated by a doctor. Overuse injuries such as ligament strains and tears are common injuries for teenage athletes. Correct conditioning and enough rest can help prevent overuse injuries.

Stretching after activity may help prevent injuries. Regular stretching improves the flexibility of muscles and tendons. It also improves the range of mobility of your joints. Stretching can also improve your posture, and may help prevent some aches and pains caused by tight muscles.

Lesson Summary

- Bones, cartilage, and ligaments make up the skeletal system. The skeleton supports the body against the pull of gravity. The skeleton provides a framework that supports and protects the soft organs of the body. Bones work together with muscles as simple mechanical lever systems to move the body. Blood cells are made mostly inside the bone marrow. Bones store calcium.
- There are three types of joints in the body: *fixed, partly movable*, and *movable*. Fixed joints do not allow any bone movement. Partly movable joints allow only a little movement. Movable joints allow movement and provide mechanical support for the body. Joints are a type of lever, which is a rigid object that is used to increase the mechanical force that can be applied to another object. Joints reduce the amount of energy that is spent moving the body around. Calcium and vitamin D are two of the most important nutrients for a healthy skeletal system.
- Bones need calcium to grow properly. Vitamin D deficiency results in problems with bone growth and hardening. Osteoporosis is a disease in which bones become lighter and more porous than they should be. Light and porous bones are more likely to break than dense bones. Osteomalacia is a bone disease in which the bones do not harden properly and they can break easily. Osteoarthritis is a condition in which the cartilage at the ends of the bones breaks down. The break down of the cartilage leads to pain and stiffness in the joint. A sprain is an injury to a ligament. A fracture is a break or crack in a bone.

Review Questions

1. What are the organs of the skeletal system?
2. Name one tissue of the skeletal system.
3. List four functions of the skeletal system.
4. Name three types of movable joints.
5. “All joints in the body are movable.” Do you agree with this statement? Explain why or why not. **(Intermediate**
6. How are the joints in your body similar to levers?
7. Why is calcium important for a healthy skeletal system?
8. The recommended daily amount of calcium for teenagers is 1300 mg. If a person gets only 1000 mg a day, what percentage of the recommended daily amount are they getting?

9. Name two things you can do to keep your skeletal system healthy.
10. What part of the skeletal system does osteoarthritis affect?
11. Why might a doctor need to insert pins into a broken bone?

Further Reading / Supplemental Links

- http://www.girlshealth.gov/bones
- [http://www.cdc.gov/nccdphp/dnpa/nutrition/nutrition_for_everyone/basics/calcium.htm http://www.cdc.gov/nccdphp/dnpa/nutrition/nutrition_for_everyone/basics/calcium.htm
- http://en.wikipedia.org/wiki

Vocabulary

ball and socket joint Joint structure in which the ball-shaped surface of one bone fits into the cuplike depression in another bone; examples include the shoulder and hip joints.

bone marrow Soft connective tissue found inside many bones; site of blood cell formation.

cartilage Smooth covering found at the end of bones; made of tough collagen protein fibers; creates smooth surfaces for the easy movement of bones against each other.

compact bone The dense, hard outer layer of a bone.

fracture Bone injury, often called a "break;" usually caused by excess bending stress on bone.

gliding joint Joint structure that allows one bone to slide over the other; examples includes the joints in the wrists and ankles.

hinge joint Joint structure in which the ends of bones are shaped in a way that allows motion in two directions only (forward and backward); examples include the knees and elbows.

joint Point at which two or more bones meet.

ligaments Fibrous tissue that connects bones to other bones; made of tough collagen fibers.

movable joint Most mobile type of joint; the most common type of joint in the body.

osteoarthritis A condition in which the cartilage at the ends of the bones breaks down.

osteoporosis Disease in which bones become lighter and more porous than normal.

periosteum Tough, shiny, white membrane that covers all surfaces of bones.

pivot joint Joint structure in which the end on one bone rotates within a ring-type structure which can be made partly of bone and partly of ligament; example includes the joint between the radius and ulna.

skeletal system Body system that is made up of bones, cartilage, and ligaments.

skeleton Sturdy scaffolding of bones and cartilage that is found inside vertebrates.

spongy bone Lighter and less dense than compact bone; found toward the center of the bone.

sprain A ligament injury; usually caused by the sudden overstretching of a joint which causes tearing.

Points to Consider

- How does your skeletal system interact with your muscular system?
- How might a broken bone affect the functioning of the muscular system?
- How do tendons differ from ligaments? How are they similar?

16.4 Lesson 16.4: The Muscular System

Lesson Objectives

- Identify the three muscle types in the body.
- Describe how skeletal muscles and bones work together to move the body.
- Describe how exercise affects the muscular system.
- Identify two types of injuries to the muscular system.

Check Your Understanding

- What is muscle tissue?
- What is the function of the muscular system?

Introduction

The **muscular system** is the body system that allows us to move. You depend on many muscles to keep you alive. Your heart, which is mostly muscle, pumps blood around your body. Muscles are always moving in your body. Certain muscle movements happen without you thinking about them, while you can control other muscle movements. In this lesson you will learn about the different types of muscles in your body and how your muscular system works with the other body systems to keep you alive and healthy. You will also learn how and why regular physical activity is important for good health.

Types of Muscles

Each muscle in the body is made up of cells called muscle fibers. **Muscle fibers** are long, thin cells that can do something that other cells cannot do—they are able to get shorter. Shortening of muscle fibers is called *contraction*. Nearly all movement in the body is the result of muscle contraction.

You are aware of and can control certain muscle movements. Other muscle movements you are not aware of and cannot control. Muscles that you can control are called *voluntary muscles*. Muscles that you cannot control are called *involuntary muscles*. There are three different types of muscles in the body (**Figure** 16.22): *skeletal*, *smooth*, and *cardiac* muscle. Skeletal muscle is voluntary muscle. Smooth muscle and cardiac muscle are involuntary muscles.

- **Skeletal muscle** is usually attached to the skeleton. Skeletal muscles move the body. They usually contract voluntarily, but they can contract involuntarily by reflexes. For example, you can choose to move your arms, but your arm would move automatically if you were to burn your finger on a stove top.
- **Smooth muscle** is found within the walls of organs and structures such as the esophagus, stomach, intestines, and blood vessels. Unlike skeletal muscle, smooth muscle is involuntary muscle which means it not under your control.
- **Cardiac muscle** is also an involuntary muscle but is a specialized kind of muscle found only in the heart.

Figure 16.22: There are three types of muscles in the body: cardiac, skeletal, and smooth. Everyone has the same three types of muscle tissue, no matter their age. (15)

Muscles, Bones, and Movement

Skeletal muscles are attached to the skeleton by tendons. A **tendon** is a tough band of connective tissue that connects a muscle to a bone. Tendons are similar to ligaments except that ligaments join bone to each other. Muscles move the body by contracting against the skeleton. When muscles contract they get shorter, when they relax, they get longer. By contracting and relaxing, muscles pull on bones and allow the body to move. Muscles work together in pairs. Each muscle in the pair works against the other to move bones at the joints of the body. The muscle that contracts to cause a joint to bend is called the **flexor**. The muscle that contracts to cause the joint to straighten is called the **extensor**.

For example, the biceps and triceps muscles work together to allow you to bend and straighten your elbow. Your biceps muscle, shown in **Figure** 16.23, contracts, and at the same time the triceps muscle relaxes. The contracting biceps pull on the radius bone and the elbow bends. To straighten the arm, the biceps muscle relaxes and the triceps on the opposite side of the elbow joint contracts. The biceps is the flexor and the triceps is the extensor of your elbow joint. In this way the joints of your body act like levers. This lever action of your joints reduces the amount of energy you have to spend to make large body movements.

Muscles and the Nervous System

Muscles are controlled by the nervous system (see the *Controlling the Body* chapter). Nerves send messages to the muscular system from the brain. Nerves also send messages to the brain from the muscles. Remember that smooth and cardiac muscles are involuntary muscles. This means that you cannot control the nerve messages that get sent to and from these muscles.

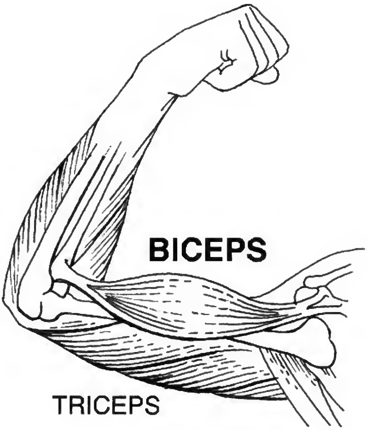


Figure 16.23: The biceps and triceps act against one another to bend and straighten the elbow joint. To bend the elbow, the biceps contract and the triceps relax. To straighten the elbow, the triceps contract and the biceps relax. (30)

For example, you cannot make your heart muscle stop beating. Likewise, you cannot make food stop moving through your intestines. You can however control the movement of your skeletal muscle. When you want to move your foot, electrical messages called *impulses* move along nerve cells from your brain to the muscles of your foot. At the point at which the nerve cell and muscle cells meet, the electrical message is converted to a chemical message. The muscle cells receive the chemical message, which causes tiny protein fibers inside the muscle cells to get shorter. The muscles contract, pulling on the bones, and your foot moves.

Contraction

A **muscle contraction** occurs when a **muscle fiber**, which is a muscle cell, generates tension through the movement of **actin** and **myosin**, two of the proteins involved in this process (see below).

Each muscle fiber contains cellular proteins and hundreds or thousands of myofibrils. Each **myofibril** is a long, cylindrical organelle that is made up of two types of protein filaments: actin and myosin. The actin filament is thin and threadlike, while the myosin filament is thicker. Myosin has a "head" region that uses energy from ATP to "walk" along the actin thin filament (**Figure** 16.24). The overlapping arrangement of actin and myosin filaments gives skeletal muscle its striated appearance. The actin and myosin filaments are organized into repeating units called sarcomeres, which can be seen in **Figure** 16.24. The sarcomeres stretch from one Z-line to the next, with thin actin filaments anchored to these Z lines. When each end of the myosin thick filament moves along the actin filament, the two actin filaments at opposite sides of the sacromere are drawn closer together and the sarcomere shortens, as shown in **Figure** 16.25. When a muscle fiber contracts, all sarcomeres contract at the same time, which pulls on the fiber ends.

The Sliding Filament Theory

The widely accepted theory of how muscles contract is called the **sliding-filament model** (also known as the **sliding filament theory**), which is shown in **Figure** 16.26. The presence of calcium ions (Ca^{2+}) allows for the interaction of actin and myosin. In the resting state, these two proteins are prevented from coming into contact. Two other proteins, troponin and tropomyosin, act as a barrier between the actin and myosin, preventing contact between them. When Ca^{2+} binds to the actin filament, the shape of the troponin-tropomyosin complex changes, allowing actin and myosin to contact with each other. Below is an outline of the sliding filament theory.

1. Once an action potential (see the *Controlling the Body* chapter) reaches a muscle fiber, the action potential spreads through the muscle fiber's network, activating specialized storage sites throughout the muscle, called the **sarcoplasmic reticulum**, to release

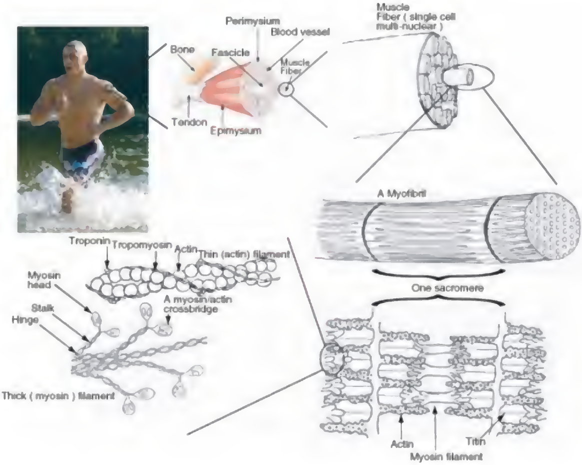


Figure 16.24: The components of muscle contraction. The **sacromere** is the functional unit of muscle contraction; it reaches from one Z-line to the next (labeled Z-disk in **Figure** 16.25). In a relaxed muscle, the actin (thin filament) and myosin (thick filament) overlap. In a muscle contraction, the filaments slide past each other, shortening the sacromere. This model of contraction is called the sliding filament model. (4)

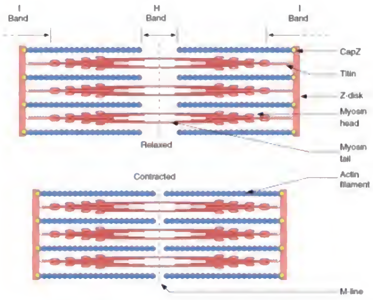


Figure 16.25: When each end of the myosin thick filament moves along the actin filament, the two actin filaments at opposite sides of the sacromere are drawn closer together and the sarcomere shortens. (10)

calcium ions (Ca^{++}). The sarcoplasmic reticulum is a special type of smooth endoplasmic reticulum found in smooth and skeletal muscle that contains large amounts of Ca^{++}.

2. The calcium ions bind to actin filaments of the myofibrils and activate the actin for attachment by the myosin heads filaments.
3. Activated myosin binds strongly to the actin filament. Upon strong binding, myosin rotates at the myosin-actin junction, which bends a region in the "neck" of the myosin "head," as shown in the **Figure** below.
4. Shortening of the muscle fiber occurs when the *bending neck* of the myosin region pulls the actin and myosin filaments across each other. Meanwhile, the myosin heads remain attached to the actin filament, as shown in **Figure** 16.26.
5. The binding of ATP allows the myosin heads to detach from actin. While detached, ATP breaks down to adenosine diphosphate and an inorganic phosphate (ADP + Pi). The breaking of the chemical bond in ATP gives energy to the myosin head, allowing it to bind to actin again.
6. Steps 4 and 5 repeat as long as ATP is available and Ca^{++} is present on the actin filament. The collective bending of numerous myosin heads (all in the same direction) moves the actin filament relative to the myosin filament which causes a shortening of the sacromere. Overall, this process results in muscle contraction. The sarcoplasmic reticulum actively pumps Ca^{++} back into itself. Muscle contraction stops when Ca^{++} is removed from the immediate environment of the myofilaments.

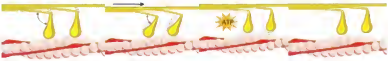


Figure 16.26: The process of actin and myosin sliding past one another is called crossbridge cycling, and it occurs in all muscle types. Myosin is a molecular motor that moves along the passive actin. Each thick myosin filament has little extensions or “heads,” that “walk” along the thin actin filaments during contraction. In this way the thick filament slides over thin filament. The actin filaments transmit the force generated by myosin to the ends of the muscle, which causes the muscle to shorten. (22)

Muscles and Exercise

Your muscles are important for carrying out everyday activities. The ability of your body to carry out your daily activities without getting out of breath, sore, or overly tired is called **physical fitness**. Physical fitness also describes the body’s ability to respond to emergencies and to avoid getting sick. A person can have a good level of physical fitness or a poor level of fitness. For example, a person who becomes breathless and tired after climbing a flight of stairs is not physically fit.

Physical exercise is any activity that maintains or improves physical fitness and overall health. Regular physical exercise is important in preventing lifestyle diseases such as heart disease, cardiovascular disease, Type 2 diabetes, and obesity.

Regular exercise improves the health of the muscular system. Muscles that are exercised are bigger and stronger than muscles that are not exercised. Exercise improves both muscular strength and muscular endurance. **Muscular strength** is the ability of a muscle to exert force during a contraction. **Muscular endurance** is the ability of a muscle to continue to contract over a long time without getting tired. Two types of exercises help improve the fitness of muscles, *anaerobic exercise* and *aerobic exercise*.

Exercises are grouped into three types depending on the effect they have on the body:

- **Aerobic exercises** such as cycling, walking, and running, increase muscular endurance.
- **Anaerobic exercises** such as weight training, or sprinting increase muscle strength.
- **Flexibility exercises** such as stretching, improve the range of motion of muscles and joints. Regular stretching helps avoid activity-related injuries.

Anaerobic Exercise and Muscular Strength

Anaerobic exercises cause muscles to get bigger and stronger. Anaerobic exercises use a resistance against which the muscle has to work to lift or push away. The resistance can be a weight or a person's own body weight, as shown in **Figure** 16.27. As a result of repeated muscle contractions, muscle fibers build up larger energy stores and the muscle tissue gets bigger. The larger a muscle is the greater the force it can apply to lift a weight or move a body joint. The muscles of weight lifters are large, and are therefore strong.

Figure 16.27: Anaerobic exercises involve the muscles working against resistance. In this case the resistance is the person's own body weight. (11)

Aerobic Exercise and Muscular Endurance

Aerobic exercises are exercises that cause your heart to beat faster and allow your muscles to use oxygen to contract. Aerobic exercise causes many different changes in skeletal muscle. Muscle energy stores are increased, the ability to use oxygen improves, and more capillaries surround the muscle fibers. These changes result in the ability of the muscle to avoid getting tired, and to use oxygen and food more efficiently. Aerobic exercise also helps improve cardiac muscle. It results in the heart being able to pump a larger volume of blood with each beat due to an increase in the size of the heart's ventricles. Examples of an aerobic exercise are shown in **Figure** 16.28.

Both aerobic and anaerobic exercises also improve the ability of the heart to pump blood around the body. Aerobic exercise causes the heart to get bigger, and anaerobic exercise causes the walls of the heart to get thicker. These changes allow the heart to push more blood throughout the body with every heartbeat.

Keeping Muscles Healthy

Being physically active for 60 minutes a day for at least five days a week improves your physical fitness. Being physically active can also help you to reduce your risk of developing

Figure 16.28: When done regularly, aerobic activities such as cycling, make the heart stronger. (26)

diseases such as cardiovascular disease, Type 2 diabetes, obesity, and certain forms of cancer. Being physically active does not mean you have to do boring workouts. You do not have to join a gym or be in a sports team to be physically active. Physical activities can include everyday things such as walking your dog, vacuuming or sweeping, cycling to school, skating, or climbing a flight of stairs (**Figure** 16.29).

Figure 16.29: Adding more physical activity in your daily life does not mean boring or expensive activities, it can be fun! Local and community pools often run swim classes that do not cost a lot, and are designed for beginners. (19)

Muscle Injuries

Sometimes muscles and tendons get injured when a person starts doing an activity before they have warmed up properly. A **warm up** is a slow increase in the intensity of a physical activity that prepares muscles for an activity. Warming up increases the blood flow to the muscles and increases the heart rate. Warmed-up muscles and tendons are less likely to get injured. For example, before running or playing soccer, a person might jog slowly to warm muscles and increase their heart rate. It is important that warm ups prepare the muscles that are to be used in the activity. Even elite athletes need to warm up, as shown in **Figure** 16.30. Some injuries are caused by overuse. An overuse injury happens if the muscle or joint is not rested enough between activities.

A **strain** is an injury to a muscle in which the muscle fibers tear because the muscle contracts too much or contracts before the muscle is warmed up. Strains are also known as *pulled muscles*. Overuse injuries often involve tendons. Overuse of tendons can cause tiny tears within the protein fibers of the tendon, which gradually weakens the tissue. These tiny tears lead to swelling, pain, and stiffness; a condition called **tendinitis**. Tendinitis can affect any tendon that is overused. Strains and tendinitis are usually treated with rest, cold compresses, and stretching exercises that a physical therapist designs for each patient.

Figure 16.30: Warming up before the game helps the players avoid injuries. Some warm-ups may include stretching exercises. Some researchers believe stretching before activities may help prevent injury. (18)

Proper rest and recovery are also as important to health as exercise is. If you do not get enough rest, your body will become injured and will not improve or react well to exercise. It is important to remember to allow enough recovery time for muscles and tendons to rest between exercise sessions. You can rest muscles by doing a different activity to what you

normally do. For example, if you run, you can rest your running muscles and joints by swimming. This type of rest is called *active rest*.

Anabolic steroids are hormones that cause the body to build up more protein in its cells. Muscle cells, which contain a lot of protein, get bigger when exposed to anabolic steroids. Your body naturally makes small amounts of anabolic steroids. They help your body repair from injury, and help to build bones and muscles. Anabolic steroids are used as medicines to treat people that have illnesses that affect muscle and bone growth. However, some people who do not need anabolic steroid as medicine try to increase their muscle size by taking these steroids. When taken in this way, anabolic steroids can have long-term affects other body systems. They can damage the person's kidneys, heart, liver, and reproductive system. If taken by adolescents, anabolic steroids can cause bones to stop growing, resulting in stunted growth.

Lesson Summary

- The body has three types of muscle tissue: skeletal, cardiac, and smooth. Muscles move the body by contracting against the skeleton. Muscles are controlled by the nervous system.
- Nerves send messages to the muscular system from the brain. Nerves also send messages to the brain from the muscles. Regular exercise improves the health of the muscular system. Muscles that are exercised are bigger and stronger than muscles that are not exercised.
- Exercise improves both muscular strength and muscular endurance. Muscular strength is the ability of a muscle to exert force during a contraction. Muscular endurance is the ability of a muscle to continue to contract over a long time without getting tired. Identify two types of injuries to the muscular system.
- A strain is an injury to a muscle in which the muscle fibers tear because the muscle contracts too much or contracts before the muscle is warmed up. Tiny tears and swelling in a tendon results in tendinitis.

Review Questions

1. Name the three types of muscle tissue in the body.
2. Which of the three types of muscles in the body are voluntary?
3. What is another name for muscle cells?
4. Describe how skeletal muscles and bones work together to move the body.
5. What is a tendon?
6. How does aerobic exercise affect the heart?
7. How does aerobic exercise affect skeletal muscle?
8. How does anaerobic exercise affect skeletal muscle?
9. What is a muscle strain?

10. Why is warming up before exercise a good idea?
11. Why are taking anabolic steroids a dangerous way to try to build up muscles?

Further Reading / Supplemental Links

- http://www.hmc.psu.edu/healthinfo/m/musclestrain.htm
- http://www.cdc.gov/nccdphp/dnpa/physical/everyone/index.htm
- http://en.wiki.org

Vocabulary

aerobic exercises Types of exercises that cause the heart to beat faster and allow the muscles to obtain energy to contract by using oxygen.

anabolic steroids Hormones that cause the body to build up more protein in its cells.

anaerobic exercise Types of exercises that involve short bursts of high-intensity activity; forces the muscles to obtain energy to contract without using oxygen.

cardiac muscle An involuntary and specialized kind of muscle found only in the heart.

contraction Shortening of muscle fibers.

extensor The muscle that contracts to cause a joint to straighten.

flexibility exercises Stretching exercises that improve the range of motion of muscles and joints.

flexor The muscle that contracts to cause a joint to bend.

involuntary muscle A muscle that a person cannot consciously control; cardiac muscle and smooth muscle are involuntary.

muscle cells Long, thin cells that can contract; also called muscle fibers.

muscle fibers Long, thin cells that can contract; also called muscle cells.

muscular endurance The ability of a muscle to continue to contract over a long time without getting tired.

muscular strength The ability of a muscle to exert force during a contraction.

muscular system The body system that allows movement.

physical exercise Any activity that maintains or improves physical fitness and overall health.

physical fitness The ability of your body to carry out your daily activities without getting out of breath, sore, or overly tired.

skeletal muscle The muscle that is usually attached to the skeleton.

smooth muscle Involuntary muscle found within the walls of organs and structures such as the esophagus, stomach, intestines, and blood vessels.

strain An injury to a muscle in which the muscle fibers tear because the muscle contracts too much or contracts before the muscle is warmed up.

tendinitis A condition in which tiny tears form in the protein fibers of the tendon and gradually weaken the tissue.

tendon A tough band of connective tissue that connects a muscle to a bone.

voluntary muscle A muscle that a person can consciously control; skeletal muscle is voluntary.

warm-up A slow increase in the intensity of a physical activity that prepares muscles for an activity.

Points to Consider

- How does your muscular system depend on your digestive system?
- How does what you choose to eat affect your muscular system and your skeletal system?

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Chapter 17

Food and the Digestive System

17.1 Lesson 17.1: Food and Nutrients

Lesson Objectives

- Explain why the body needs food.
- Identify the roles of carbohydrates, proteins, and lipids.
- Give examples of vitamins and minerals, and state their functions.
- Explain why water is a nutrient.

Check Your Understanding

- What are the four types of organic compounds?
- What do all cells need in order to function?
- What are muscles made of?

Introduction

Did you ever hear the old saying "An apple a day keeps the doctor away"? Do apples really prevent you from getting sick? Probably not, but eating apples and other fresh fruits can help keep you healthy. The girl shown in **Figure** 17.1 is eating fresh vegetables as part of a healthy meal. Why do you need foods like these for good health? What roles does food have in the body?

Figure 17.1: This girl is eating a salad of tomatoes and leafy green vegetables. Fresh vegetables such as these are excellent food choices for good health. (14)

Why We Need Food

Your body needs food for three reasons:

- Food gives your body energy. You need energy for everything you do.
- Food provides building materials for your body. Your body needs building materials so it can grow and repair itself.
- Food contains substances that help control body processes. Your body processes must be kept in balance for good health. For example, your body needs the right balance of water and salts.

For all these reasons, you must have a steady supply of nutrients. **Nutrients** are chemicals in food that your body needs. There are six types of nutrients: carbohydrates, proteins, lipids, vitamins, minerals, and water. Carbohydrates, proteins, and lipids give your body energy. Proteins provide building materials. Proteins, vitamins, and minerals help control body processes.

Nutrients that Provide Energy

Molecules of carbohydrates, proteins, and lipids contain energy. When your body digests food, it breaks down the molecules of these nutrients. This releases the energy so your body can use it. The energy in food is measured in units called **Calories.**

Carbohydrates

Carbohydrates are nutrients that include sugars, starches, and fiber. How many grams of carbohydrates you need each day are shown in **Figure** 17.2. It also shows some foods that are good sources of carbohydrates.

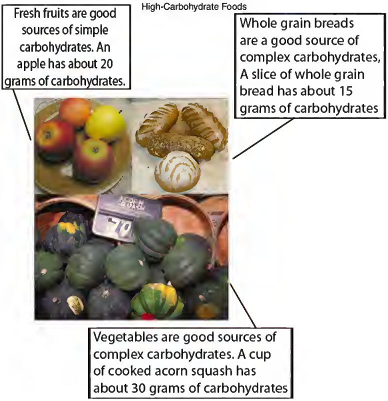

Figure 17.2: Up to the age of 13 years, you need about 130 grams of carbohydrates a day. Most of the carbohydrates should be complex. They are broken down by the body more slowly than simple carbohydrates. Therefore, they provide energy longer and more steadily. What other foods do you think are good sources of complex carbohydrates? (6)

Sugars are small, simple carbohydrates that are found in foods such as fruits and milk. The sugar found in fruits is called fructose. The sugar found in milk is called lactose. These sugars are broken down by the body to form glucose, the simplest sugar of all. Glucose is used by cells for energy. Remember the discussion of cellular respiration in the *Cell Functions* chapter? Cellular respiration turns glucose into the usable form of chemical energy, ATP. One gram of sugar provides your body with four Calories of energy.

Some people cannot digest lactose, the sugar in milk. This condition is called lactose intolerance. If people with this condition drink milk, they may have cramping, bloating, and gas. To avoid these symptoms, they should not drink milk, or else they should drink special, lactose-free milk.

Starches are large, complex carbohydrates. They are found in foods such as vegetables and grains. Starches are broken down by the body into sugars that provide energy. Like sugar, one gram of starch provides your body with four Calories of energy.

Fiber is another type of large, complex carbohydrate. Unlike sugars and starches, fiber does not provide energy. However, it has other important roles in the body. There are two types of fiber found in food: soluble fiber and insoluble fiber. Each type has a different role.

- Soluble fiber dissolves in water. It helps keep sugar and fat at normal levels in the blood.
- Insoluble fiber does not dissolve in water. As it moves through the large intestine, it absorbs water. This helps keep food waste moist so it can pass easily out of the body.

Eating foods high in fiber helps fill you up without providing too many Calories. Most fruits and vegetables are high in fiber. Some examples are shown in **Figure** 17.3.

Proteins

Proteins are nutrients made up of smaller molecules called amino acids. As discussed in the *Introduction to Living Things* chapter, the amino acids are arranged like "beads on a string." These amino acid chains then fold up into a three-dimensional molecule. Proteins have several important roles in the body. For example, proteins:

- Make up muscles.
- Help control body processes.
- Help the body fight off bacteria and other "foreign invaders."
- Carry substances in the blood.

If you eat more proteins than you need for these purposes, the extra proteins are used for energy. One gram of protein provides four Calories of energy. This is the same amount as one gram of sugar or starch. How many grams of proteins you need each day are shown in **Figure** 17.4. It also shows some foods that are good sources of proteins.

There are many different amino acids, the building blocks of proteins, but your body needs only 20 of them. Your body can make ten of these amino acids from simpler substances. The other ten amino acids must come from the proteins in foods. These ten are called essential amino acids. Only animal foods, such as milk and meat, contain all ten essential amino acids in a single food. Plant foods are missing one or more essential amino acids. However, by eating a combination of plant foods, such as beans and rice, you can get all ten essential amino acids.

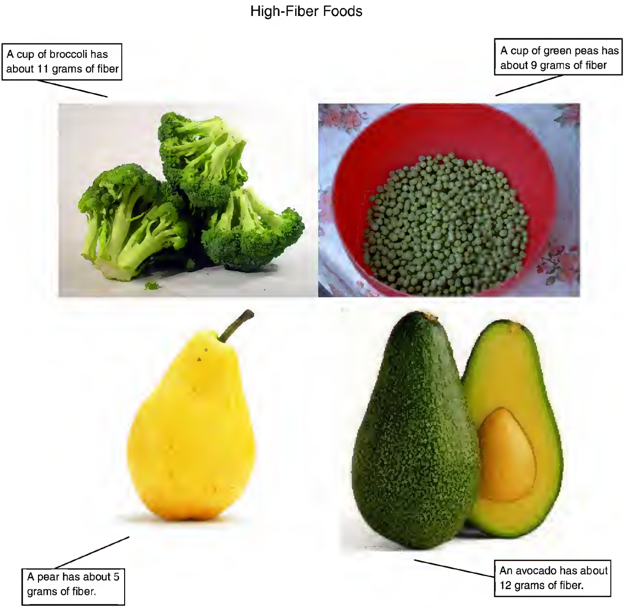

Figure 17.3: Between the ages of 9 and 13 years, girls need about 26 grams of fiber a day, and boys need about 31 grams of fiber a day. Do you know other foods that are high in fiber? (10)

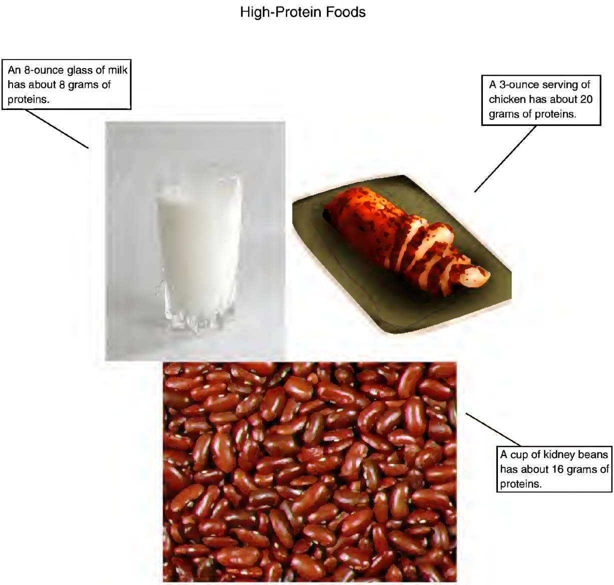

Figure 17.4: Between the ages of 9 and 13 years, you need about 34 grams of proteins a day. What other foods do you think are good sources of proteins? (5)

Lipids

Lipids are nutrients such as fats that store energy. The heart and skeletal muscles rely mainly on lipids for energy. One gram of lipids provides nine Calories of energy. This is more than twice the amount provided by carbohydrates or proteins. Lipids have several other roles in the body. For example, lipids:

- Protect nerves.
- Help control blood pressure.
- Help blood to clot.
- Make up the membranes that surround cells.

Fats are one type of lipid. Fat is the main form in which the body stores energy. Stored fat gives your body an energy reserve. It's like having money in a savings account. It's there in case you need it. Stored fat also cushions and protects internal organs. In addition, it insulates the body. It helps keep you warm in cold weather.

Fats and other lipids are necessary for life. However, they can be harmful if you eat too much of them, or the wrong type of fats. Fats can build up in the blood and damage blood vessels. This increases the risk of heart disease. There are two types of lipids: saturated lipids and unsaturated lipids.

- Saturated lipids are harmful even in very small amounts. They should be avoided as much as possible. Saturated fats are found mainly in animal foods, such as meats, whole milk, and eggs. Saturated fats increase cholesterol levels in the blood. Cholesterol is a fatty substance that is found naturally in the body. Too much cholesterol in the blood can lead to heart disease. It is best to limit the amount of saturated fats in your diet.
- Unsaturated lipids are found mainly in plant foods, such as vegetable oil, olive oil, and nuts. Unsaturated lipids are also found in fish such as salmon. Unsaturated lipids are needed in small amounts for good health because your body cannot make them. Most lipids and fats in your diet should be unsaturated.

Another type of lipid is called **trans fat**. Trans fat is manufactured and added to certain foods to keep them fresher for longer. Foods that contain trans fats include cakes, cookies, fried foods, and margarine. Eating foods that contain trans fats increases the risk of heart disease. You should do your best to eat fewer foods that contain it. Beginning in 2010, California will ban trans fats from restaurant products, and, beginning in 2011, from all retail baked goods.

Vitamins and Minerals

Vitamins and minerals are also nutrients. They do not provide energy. However, they are needed for good health.

Vitamins

Vitamins are substances that the body needs in small amounts to function properly. Humans need 13 different vitamins. Some of them are listed in **Table** (17.1) . The table also shows how much of each vitamin you need each day. Vitamins have many roles in the body. For example, Vitamin A helps maintain good vision. Vitamin B_9 helps form red blood cells. Vitamin K is needed for blood to clot when you have a cut or other wound.

Table 17.1: **Vitamins Needed For Good Health**

Vitamin	One Reason You Need It	Some Foods that Have It	How Much of It You Need Each Day (at ages 9–13 years)
Vitamin A	Needed for good vision	Carrots, spinach, milk, eggs	600 g (1 g = 1 x 10^{-6} g)
Vitamin B_1	Needed for healthy nerves	Whole wheat, peas, meat, beans, fish, peanuts	0.9 mg (1 mg = 1 x 10^{-3} g)
Vitamin B_3	Needed for healthy skin and nerves	Beets, liver, pork, turkey, fish, peanuts	12 mg
Vitamin B_9	Needed to make red blood cells	Liver, peas, dried beans, green leafy vegetables	300 g
Vitamin B_{12}	Needed for healthy nerves	Meat, liver, milk, shellfish, eggs	1.8 g
Vitamin C	Needed for growth and repair of tissues	Oranges, grapefruits, red peppers, broccoli	45 mg
Vitamin D	Needed for healthy bones and teeth	Milk, salmon, tuna, eggs	5 g
Vitamin K	Needed for blood to clot	Spinach, Brussels sprouts, milk, eggs	60 g

Some vitamins are produced in the body. For example, vitamin D is made in the skin when it is exposed to sunlight. Vitamins B_{12} and K are produced by bacteria that normally live inside the body. Most other vitamins must come from foods. Foods that are good sources of vitamins are listed in **Table 1**. They include whole grains, vegetables, fruits, and milk.

Not getting enough vitamins can cause health problems. For example, too little vitamin C causes a disease called scurvy. People with scurvy have bleeding gums, nosebleeds, and other symptoms. Getting too much of some vitamins can also cause health problems. The vitamins to watch out for are vitamins A, D, E, and K. These vitamins are stored by the body, so they can build up to high levels. Very high levels of these vitamins can even cause

death, although this is very rare.

Minerals

Minerals are chemical elements that are needed for body processes. Minerals that you need in relatively large amounts are listed in **Table** (17.2). Minerals that you need in smaller amounts include iodine, iron, and zinc. Minerals have many important roles in the body. For example, calcium and phosphorus are needed for strong bones and teeth. Potassium and sodium are needed for muscles and nerves to work normally.

Table 17.2: **Minerals Needed For Good Health.**

Mineral	One Reason You Need It	Some Foods that Have It	How Much of It You Need Each Day (at ages 9–13 years)
Calcium	Needed for strong bones and teeth	Milk, soy milk, green leafy vegetables	1,300 mg
Chloride	Needed for proper balance of water and salts in body	Table salt, most packaged foods	2.3 g
Magnesium	Needed for strong bones	Whole grains, green leafy vegetables, nuts	240 mg
Phosphorus	Needed for strong bones and teeth	Meat, poultry, whole grains\	1,250 mg
Potassium	Needed for muscles and nerves to work normally	Meats, grains, bananas, orange juice	4.5 g
Sodium	Needed for muscles and nerves to work normally	Table salt, most packaged foods	1.5 g

Your body cannot produce any of the minerals that it needs. Instead, you must get minerals from the foods you eat. Good sources of minerals are listed in **Table** (17.2). They include milk, green leafy vegetables, and whole grains.

Not getting enough minerals can cause health problems. For example, too little calcium may cause osteoporosis. This is a disease in which bones become soft and break easily. Getting too much of some minerals can also cause health problems. Many people get too much sodium. Sodium is added to most packaged foods. People often add more sodium to their food by using table salt (sodium chloride). Too much sodium causes high blood pressure in some people.

Water

Did you know that water is also a nutrient? By weight, your cells are about two-thirds water, so you cannot live without it. In fact, you can survive for only a few days without water. You lose water in each breath you exhale. You also lose water in sweat and urine. If you do not take in enough water to replace the water that you lose, you may develop dehydration. Symptoms of dehydration include dry mouth, headaches, and feeling dizzy. Dehydration can be very serious. Severe dehydration can even cause death.

When you exercise, especially on a hot day, you lose more water in sweat than you usually do. You need to drink extra water before, during, and after exercise. The children in **Figure 17.5** are drinking water while playing outside on a warm day. They need to drink water to avoid dehydration.

Figure 17.5: When you are active outside on a warm day, it's important to drink plenty of water. You need to replace the water you lose in sweat. (8)

Getting too much water can also be dangerous. Excessive water may cause a condition called hyponatremia. In this condition, water collects in the brain and causes it to swell.

Hyponatremia can cause death. It requires emergency medical care.

Lesson Summary

- The body needs food for energy, building materials, and substances that help control body processes.
- Carbohydrates, proteins, and lipids provide energy and have other important roles in the body.
- Vitamins and minerals do not provide energy but are needed in small amounts for the body to function properly.
- The body must have water to survive.

Review Questions

1. What are three reasons that your body needs food?
2. Which nutrients can be used for energy?
3. Name two types of fiber and state the role of each type of fiber in the body.
4. What are some foods that are good sources of vitamin C?
5. What are two minerals that are needed for strong bones and teeth?
6. List some of the functions of proteins in the body. Based on your list, predict health problems people might have if they do not get enough proteins in foods.
7. Your body needs 20 different amino acids. Why do you need to get only ten of these amino acids from food? Name foods you can eat to get these ten amino acids.
8. Compare and contrast saturated and unsaturated lipids.
9. Identify three vitamins that are produced in the body. How are they produced?
10. Why do you need to drink extra water when you exercise on a hot day? What might happen if you did not drink extra water?

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Vocabulary

calories Units used to measure the energy in food.

carbohydrates Nutrients that include sugars, starches, and fiber; give your body energy; organic compound.

essential amino acids Amino acids that must come from the proteins in foods; you cannot make these amino acids.

insoluble fiber Large, complex carbohydrate; does not dissolve in water; moves through the large intestine and helps keep food waste moist so it can pass easily out of the body.

lipids Nutrients such as fats that are rich in energy; organic compound.

minerals Chemical elements that are needed for body processes.

nutrients Chemicals in food that your body needs.

proteins Nutrients made up of smaller molecules called amino acids; give your body energy; help control body processes; organic compound.

saturated fats Found mainly in animal foods, such as meats, whole milk, and eggs; increase cholesterol levels in the blood.

soluble fiber Large, complex carbohydrate; dissolves in water; helps keep sugar and fat at normal levels in the blood.

starch Large, complex carbohydrate; found in foods such as vegetables and grains; broken down by the body into sugars that provide energy.

trans fat Manufactured and added to certain foods to keep them fresher for longer. Foods that contain trans fats include cakes, cookies, fried foods, and margarine.

unsaturated lipids Found mainly in plant foods, such as vegetable oil, olive oil, and nuts; also found in fish such as salmon.

vitamins Substances that the body needs in small amounts to function properly.

Points to Consider

- Think about how you can be sure you are getting enough nutrients?
- Do you think knowing the nutrients in the foods you eat are important?
- Do you have to keep track of all the nutrients you eat, or is there an easier way to choose foods that provide the nutrients you need?

17.2 Lesson 17.2: Choosing Healthy Foods

Lesson Objectives

- State how to use MyPyramid to get the proper balance of nutrients.
- Describe how to read food labels to choose foods wisely.
- Explain how to balance food with exercise.

Check Your Understanding

- What is a nutrient?
- Why do you need extra energy when you exercise?

Introduction

Foods such as whole grain breads, fresh fruits, and fish provide nutrients you need for good health. However, various foods provide different nutrients. You also need different amounts of each nutrient. How can you choose the right mix of foods to get the proper balance of nutrients? Two tools can help you choose foods wisely: MyPyramid and food labels.

MyPyramid

MyPyramid is a diagram that shows how much you should eat each day of foods from six different food groups. It recommends the amount of nutrients you need based on your age, your sex, and your levels of activity. MyPyramid is shown in **Figure** 17.6. The six food groups in MyPyramid are:

- Grains—such as bread, rice, pasta, and cereal.
- Vegetables—such as spinach, broccoli, carrots, and sweet potatoes.
- Fruits—such as oranges, apples, bananas, and strawberries.
- Oils—such as vegetable oil, canola oil, olive oil, and peanut oil.
- Milk—such as milk, yogurt, cottage cheese, and other cheeses.

- Meat and beans—such as chicken, fish, soybeans, and kidney beans.

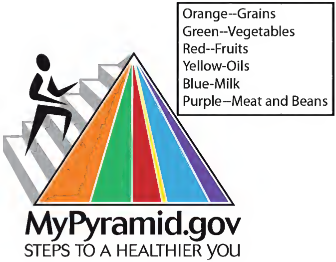


Figure 17.6: MyPyramid can help you choose foods wisely for good health. Each colored band represents a different food group. The key shows which food group each color represents. Which colored band of MyPyramid is widest? Which food group does it represent? (3)

Using MyPyramid

In MyPyramid, each food group is represented by a band of a different color. For example, grains are represented by an orange band, and vegetables are represented by a green band. The wider the band, the more foods you should choose from that food group each day. The orange band in MyPyramid is the widest band. This means that you should choose more foods from the grain group than from any other single food group. The green, blue, and red bands are also relatively wide. Therefore, you should choose plenty of foods from the vegetable, milk, and fruit groups, as well. You should choose the fewest foods from the food group with the narrowest band. Which band is narrowest? Which food group does it represent?

Healthy Eating Guidelines

Did you ever hear the saying, "variety is the spice of life"? Variety is also the basis of a healthy eating plan. When you choose foods based on MyPyramid, you should choose a variety of different foods. Follow these guidelines to make the wisest food choices for

good health. Keep in mind that nutritional guidelines may change throughout life. As food provides energy and nutrients for growth and development, nutritional requirements may vary with body weight, age, sex, activity, and body functioning.

- Make at least half your daily grain choices whole grains. Examples of whole grains are whole wheat bread, whole wheat pasta, and brown rice.
- Choose a variety of different vegetables each day. Be sure to include both dark green vegetables, such as spinach and broccoli, and orange vegetables, such as carrots and sweet potatoes.
- Choose a variety of different fruits each day. Select mainly fresh fruits rather than canned fruits and whole fruits instead of fruit juices.
- When choosing oils, go for unsaturated oils, such as olive oil, canola oil, or vegetable oil.
- Choose low-fat or fat-free milk and other dairy products. For example, select fat-free yogurt and low-fat cheese.
- For meats, choose fish, chicken, and lean cuts of beef. Also, be sure to include beans, nuts, and seeds.

What about Ice Cream, Cookies, and Potato Chips?

Are you wondering where foods like ice cream, cookies, and potato chips fit into MyPyramid? The white tip of MyPyramid represents foods such as these. These are foods that should be eaten only in very small amounts and not very often. Such foods contain very few nutrients, and are called nutrient-poor. Instead, they are high in fats, sugars, and sodium, but low in other nutrients. Fats, sugars, and sodium are nutrients that you should limit in a healthy eating plan. Ice cream, cookies, and potato chips are also high in Calories. Eating too much of them may lead to unhealthy weight gain.

Food Labels

In the United States, packaged foods are required by law to have nutrition facts labels. A **nutrition facts label** shows the nutrients in a food. Packaged foods are also required to list their ingredients. An **ingredient** is a specific item that a food contains.

Using Nutrition Facts Labels

An example of a nutrition facts label is shown in **Figure** 17.7. The information listed at the right of the label tells you what to look for. At the top of the label, look for the serving size. The serving size tells you how much of the food you should eat to get the nutrients listed on the label. A cup of food from the label in **Figure** 17.7 is a serving. The Calories in one serving are listed next. In this food, there are 250 Calories per serving.

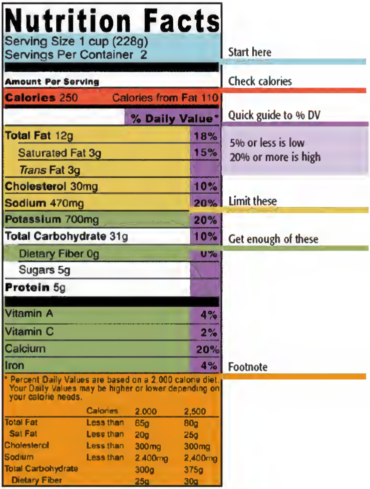
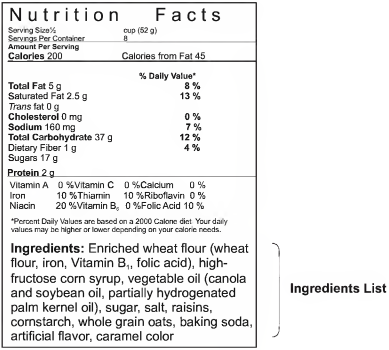


Figure 17.7: Reading nutrition facts labels can help you choose healthy foods. Look at the nutrition facts label shown here. Do you think this food is a good choice for a healthy eating plan? Why or why not? (1)

Next on the nutrition facts label, look for the percent daily values (% DV) of nutrients. A food is low in a nutrient if the percent daily value of the nutrient is 5% or less. The healthiest foods are low in nutrients such as fats and sodium. A food is high in a nutrient if the percent daily value of the nutrient is 20% or more. The healthiest foods are high in nutrients such as fiber and proteins. Look at the percent daily values on the food label in **Figure** 17.7. Which nutrients have values of 5% or less? These are the nutrients that are low in this food. They include fiber, vitamin A, vitamin C, and iron. Which nutrients have values of 20% or more? These are the nutrients that are high in this food. They include sodium, potassium, and calcium.

Using Ingredients Lists

The food label in **Figure** 17.8 includes the list of ingredients in a different food. The ingredients on food labels are always listed in descending order. This means that the main ingredient is listed first. The main ingredient is the ingredient that is present in the food in the greatest amount. As you go down the list, the ingredients are present in smaller and smaller amounts.


Nutrition Facts

Serving Size½	cup (52 g)
Servings Per Container	8
Amount Per Serving	
Calories 200	Calories from Fat 45
	% Daily Value*
Total Fat 5 g	**8 %**
Saturated Fat 2.5 g	**13 %**
Trans fat 0 g	
Cholesterol 0 mg	**0 %**
Sodium 160 mg	**7 %**
Total Carbohydrate 37 g	**12 %**
Dietary Fiber 1 g	**4 %**
Sugars 17 g	
Protein 2 g	

Vitamin A	0 %	Vitamin C	0 %	Calcium	0 %
Iron	10 %	Thiamin	10 %	Riboflavin	0 %
Niacin	20 %	Vitamin B_6	0 %	Folic Acid	10 %

*Percent Daily Values are based on a 2000 Calorie diet. Your daily values may be higher or lower depending on your calorie needs.

Ingredients: Enriched wheat flour (wheat flour, iron, Vitamin B_1, folic acid), high-fructose corn syrup, vegetable oil (canola and soybean oil, partially hydrogenated palm kernel oil), sugar, salt, raisins, cornstarch, whole grain oats, baking soda, artificial flavor, caramel color

Figure 17.8: This food label includes the list of ingredients in the food. The main ingredient is enriched wheat flour, followed by high-fructose corn syrup. Why should you avoid foods with ingredients such as these at the top of the ingredients list? (15)

Reading the ingredients lists on food labels can help you choose the healthiest foods. At the

top of the list, look for ingredients such as whole grains, vegetables, milk, and fruits. These are the ingredients you need in the greatest amounts for balanced eating. Avoid foods that list fats, oils, sugar, or salt at the top of the list. For good health, you should avoid getting too much of these ingredients. Be aware that ingredients such as corn syrup are sugars.

You should also use moderation when eating foods that contain ingredients such as white flour or white rice. These ingredients have been processed, and processing removes nutrients. The word "enriched" is a clue that an ingredient has been processed. Ingredients are enriched with added nutrients to replace those lost during processing. However, enriched ingredients are still likely to have fewer nutrients than unprocessed ingredients.

Balancing Food with Exercise

Look at MyPyramid in **Figure** 17.6. Note the person walking up the side of the pyramid. This shows that exercise is important for balanced eating. Exercise helps you use any extra energy in the foods you eat. The more active you are, the more energy you use. You should try to get at least an hour of physical activity just about every day. **Figure** 17.9 shows some activities that can help you use extra energy.

Any unused energy in food is stored in the body as fat. This is true whether the extra energy comes from carbohydrates, proteins, or lipids. What happens if you take in more energy than you use, day after day? You will store more and more fat and become overweight. Eventually, you may become obese. Obesity is having a very high percentage of body fat. Obese people are at least 20 percent heavier than their healthy weight range. The excess body fat of obesity is linked to many diseases. Obese people often have serious health problems, such as diabetes, high blood pressure, and high cholesterol. They are also more likely to develop arthritis and some types of cancer. People that remain obese throughout adulthood usually do not live as long as people that stay within a healthy weight range.

The current generation of children and teens is the first generation in our history that may have a shorter life than their parents. The reason is their high rate of obesity and the health problems associated with obesity.

You can avoid gaining weight and becoming obese. The choice is yours. Choose healthy foods by using MyPyramid and reading food labels. Then get plenty of exercise to balance the energy in the foods you eat.

Lesson Summary

- MyPyramid shows how much you should eat each day of foods from six different food groups.
- Reading food labels can help you choose the healthiest foods.
- Regular exercise helps you use extra energy and avoid unhealthy weight gain.

Figure 17.9: All of these activities are good ways to exercise and use extra energy. The Calories given for each activity are the number of Calories used in an hour by a person that weighs 100 pounds. Which of these activities uses the most Calories? Which of the activities do you enjoy? (2)

Review Questions

1. List the six food groups represented by MyPyramid.
2. Which food group contains soybeans, kidney beans, and fish?
3. What guideline should you follow in choosing foods from the grains food group?
4. Which ingredient is always listed first on a food label?
5. What happens if you take in more energy than you use, day after day?
6. Explain how you can use MyPyramid to choose foods that provide the proper balance of nutrients.
7. Why should you limit foods like ice cream and potato chips in a healthy eating plan?
8. Explain how you can use food labels to choose foods that are high in fiber.
9. Why should you try to avoid foods with processed ingredients? What are some examples of processed ingredients?
10. How does physical activity help prevent obesity?

Further Reading / Supplemental Links

- Eric Schlosser and Charles Wilson. *Chew on This: Everything You Don't Want to Know about Fast Food.* Houghton Mifflin, 2006.
- John Burstein. *The Shape of Good Nutrition: The Food Pyramid.* Crabtree Publishing Company, 2008.
- Rose McCarthy. *Food Labels: Using Nutrition Information to Create a Healthy Diet.* Rosen Publishing Group, 2008.
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- http://www.cfsan.fda.gov/~acrobat/nutfacts.pdf
- http://www.cfsan.fda.gov/~dms/foodlab.html
- http://www.fns.usda.gov/tn/parents/nutritionlabel.html
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- http://www.iom.edu/Object.File/Master/21/372/0.pdf
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- http://www.prb.org/Articles/2005/WillRisingChildhoodObesityDecreaseUSLifeExpectancy aspx
- http://www.sciencemag.org/cgi/content/summary/307/5716/1716
- http://en.wikipedia.org/wiki

Vocabulary

enriched Term used for an ingredient that has been processed; ingredients are enriched with added nutrients to replace those lost during processing; likely to have fewer nutrients than unprocessed ingredients.

ingredient A specific item that a food contains.

main ingredient The ingredient that is present in the food in the greatest amount.

MyPyramid Diagram that shows how much you should eat each day of foods from six different food groups.

nutrition facts label The label on packaged food that shows the nutrients in the food.

obesity Having a very high percentage of body fat; obese people are at least 20 percent heavier than their healthy weight range.

serving size Tells you how much of the food you should eat to get the nutrients listed on the label.

Points to Consider

- Discuss how foods may be broken down into nutrients that your body can use? For example, how do you think an apple becomes simple sugars that your body can use for energy? Or how might a piece of cheese become proteins that your body can use for building materials?

17.3 Lesson 17.3: The Digestive System

Lesson Objectives

- State the functions of the digestive system.
- Explain the role of enzymes in digestion.
- Describe the digestive organs and their functions.
- Explain the roles of helpful bacteria in the digestive system.
- List ways to help keep your digestive system healthy.

Check Your Understanding

- What is a chemical reaction?
- What is an enzyme?
- What are bacteria?

Introduction

Nutrients in the foods you eat are needed by the cells of your body. How do the nutrients in foods get to your body cells? What organs and processes break down the foods and make the nutrients available to cells? The organs are those of the digestive system. The processes are digestion and absorption.

What Does the Digestive System Do?

The **digestive system** is the body system that breaks down food and absorbs nutrients. It also gets rid of solid food waste. The main organs of the digestive system are shown in **Figure** 17.10.

Digestion is the process of breaking down food into nutrients. There are two types of digestion: mechanical digestion and chemical digestion. In mechanical digestion, large chunks of food are broken down into small pieces. This is a physical process. In chemical digestion, large food molecules are broken down into small nutrient molecules. This is a chemical process.

Absorption is the process in which substances are taken up by the blood. After food is broken down into small nutrient molecules, the molecules are absorbed by the blood. Then the nutrient molecules travel in the bloodstream to cells throughout the body.

Some substances in food cannot be broken down into nutrients. They remain behind in the digestive system after the nutrients are absorbed. Any substances in food that cannot be digested and absorbed pass out of the body as solid waste. The process of passing solid food waste out of the body is called **elimination.**

The Role of Enzymes in Digestion

Chemical digestion could not take place without the help of digestive enzymes. An **enzyme** is a protein that speeds up chemical reactions in the body. Digestive enzymes speed up chemical reactions that break down large food molecules into small nutrient molecules.

Did you ever use a wrench, like the one in **Figure** 17.11, to tighten a bolt? You could tighten a bolt with your fingers, but it would be difficult and slow. If you use a wrench, you can tighten a bolt much more easily and quickly. Enzymes are like wrenches. They make it

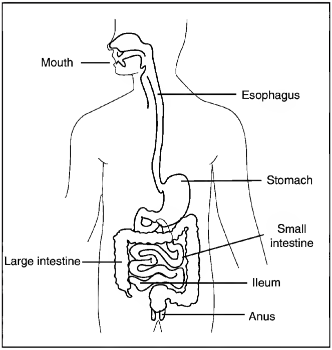

Figure 17.10: This drawing shows the major organs of the digestive system. Trace the path of food through the organs of the digestive system as you read about them in this lesson. (11)

much easier and quicker for chemical reactions to take place. Like a wrench, enzymes can also be used over and over again. But you need the appropriate size and shape of the wrench to efficiently tighten the bolt, just like each enzyme is specific for the reaction it helps.

Figure 17.11: Turning a bolt with a wrench is easier and quicker than trying to turn a bolt with your fingers. How is a wrench like an enzyme? (13)

Digestive enzymes are secreted by the organs of the digestive system. Examples of digestive enzymes are:

- Amylase is produced by the mouth. It helps break down large starches molecules into smaller sugar molecules.
- Pepsin is produced by the stomach. Pepsin is a protease; it helps break down proteins into amino acids.
- Trypsin is produced in the pancreas. Trypsin is a protease; it cleaves peptide chains.
- Pancreatic lipase is secreted by the pancreas. It is a lipase, used to break apart fats.
- Deoxyribonuclease and ribonuclease are nucleases secreted by the pancreas. They are enzymes that break bonds in nucleic acid backbones.

Bile salts are bile acids whose main function is to facilitate the processing of dietary fat. Bile acids are made in the liver. Upon eating a meal, the contents of the gallbladder are

secreted into the intestine, where bile acids break down dietary fats. Bile acids serve other functions, including eliminating cholesterol from the body.

Digestive Organs and Their Roles

The mouth and stomach are just two of the organs of the digestive system. Other digestive system organs are the esophagus, small intestine, and large intestine. From **Figure** 17.10, you can see that the digestive organs form a long tube. In adults, this tube is about 9 meters (30 feet) long! At one end of the tube is the mouth. At the other end is the anus. Food enters the mouth and then passes through the rest of the digestive system. Food waste leaves the body through the anus.

The organs of the digestive system are lined with muscles. The muscles contract, or tighten, to push food through the system. This is shown in **Figure** 17.12. The muscles contract in waves. The waves pass through the digestive system like waves through a Slinky®. This movement of muscle contractions is called **peristalsis**. Without peristalsis, food would not be able to move through the digestive system. Peristalsis is an involuntary process, which means that it occurs without your conscious control.

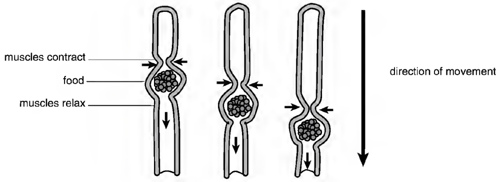

Figure 17.12: This diagram shows how muscles push food through the digestive system. Muscle contractions travel through the system in waves, pushing the food ahead of them. This is called peristalsis. (9)

The liver, gall bladder, and pancreas are also organs of the digestive system. They are shown in **Figure** 17.13. Food does not pass through these three organs. However, these organs are important for digestion. They secrete or store enzymes or other chemicals that are needed to help digest food chemically.

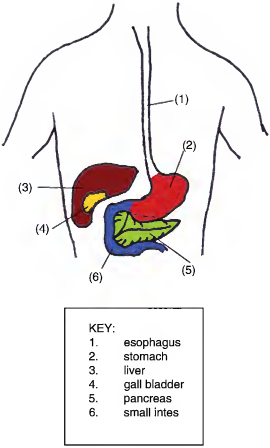

Figure 17.13: This drawing shows the liver, gall bladder, and pancreas. These organs are part of the digestive system. Food does not pass through them, but they secrete substances needed for chemical digestion. (12)

Mouth, Esophagus, and Stomach

The mouth is the first organ that food enters. However, digestion may start even before you put the first bite of food into your mouth. Just seeing or smelling food can cause the release of saliva and digestive enzymes in your mouth. Once you start eating, saliva wets the food, which makes it easier to break up and swallow. Digestive enzymes, including amylase, start breaking down starches into sugars. Your tongue helps mix the food with the saliva and enzymes.

Your teeth also help digest food. Your front teeth are sharp. They cut and tear food when you bite into it. Your back teeth are broad and flat. They grind food into smaller pieces when you chew. Chewing is part of mechanical digestion. Your tongue pushes the food to the back of your mouth so you can swallow it. When you swallow, the lump of chewed food passes down your throat to your esophagus.

The **esophagus** is a narrow tube that carries food from the throat to the stomach. Food moves through the esophagus because of peristalsis. At the lower end of the esophagus, a circular muscle controls the opening to the stomach. The muscle relaxes to let food pass into the stomach. Then the muscle contracts again to prevent food from passing back into the esophagus. Some people think that gravity moves food through the esophagus. If that were true, food would move through the esophagus only when you are sitting or standing upright. In fact, because of peristalsis, food can move through the esophagus no matter what position you are in—even upside down. Just don't try to swallow food when you upside down! You could choke if you try to swallow when you are not upright.

The **stomach** is a sac-like organ at the end of the esophagus. It has thick muscular walls. The muscles alternately contract and relax. This churns the food and helps break it into smaller pieces. The churning also mixes the food with the enzyme pepsin and other chemicals that are secreted by the stomach. The pepsin and other chemicals help digest proteins chemically.

Water, salt, and simple sugars can be absorbed into the blood from the stomach. Most other substances are broken down further in the small intestine before they are absorbed. The stomach stores food until the small intestine is ready to receive it. A circular muscle controls the opening between the stomach and small intestine. When the small intestine is empty, the muscle relaxes. This lets food pass from the stomach into the small intestine.

Small Intestine

The **small intestine** is narrow tube that starts at the stomach and ends at the large intestine (see **Figure** 17.10). In adults, the small intestine is about 7 meters (23 feet) long. It is made up of three parts: the duodenum, jejunum, and ileum. Each part has different functions.

The duodenum is the first part of the small intestine. This is where most chemical digestion takes place. Many enzymes and other chemicals are secreted here. Some are secreted by the duodenum itself. Others are secreted by the pancreas or liver.

The jejunum is the second part of the small intestine. This is where most nutrients are absorbed into the blood. The jejunum is lined with tiny "fingers" called villi. A magnified picture of villi is shown in **Figure** 17.14. Villi contain microscopic blood vessels. Nutrients are absorbed into the blood through these tiny vessels. There are millions of villi, so altogether there is a very large area for absorption to take place. In fact, villi make the inner surface area of the small intestine 1,000 times larger than it would be without them. The entire inner surface area of the small intestine is about as big as a basketball court!

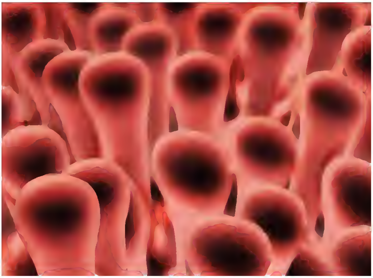

Figure 17.14: This is what the villi lining the small intestine look like when magnified. Each one is actually only about 1 millimeter long. Villi are just barely visible with the unaided eye. (7)

The ileum is the third part of the small intestine. Like the jejunum, the ileum is covered with villi. A few remaining nutrients are absorbed in the ileum. From the ileum, any remaining food waste passes into the large intestine.

The small intestine is much longer than the large intestine. So why is it called "small"? If you compare the small and large intestines in **Figure** 17.10, you will see why. The small intestine is smaller in width that the large intestine.

Large Intestine

The **large intestine** is a relatively wide tube that connects the small intestine with the anus. In adults, it is about 1.5 meters (5 feet) long. Waste enters the large intestine from the small intestine in a liquid state. As the waste moves through the large intestine, excess water is absorbed from it. After the excess water is absorbed, the remaining solid waste is

called feces. Circular muscles control the anus. They relax to let the feces pass out of the body through the anus. After feces pass out of the body, they are called stool. The excretion of stool is referred to as a bowel movement.

Liver

The **liver** has a wide range of functions, a few of which are blood detoxification, maintaining glucose balance, protein synthesis, and production of biochemicals necessary for digestion. The liver is necessary for survival; there is currently no way to compensate for the absence of liver function.

The liver is one of the most important organs in the body when it comes to detoxifying or getting rid of foreign substances or toxins, especially from the gut. The liver filters blood from the intestine. This filtering process can remove a wide range of microorganisms such as bacteria, fungi, viruses and parasites from the blood. Almost 2 quarts of blood pass through the liver every minute.

The liver also has several roles in maintaining glucose levels, including gluconeogenesis (the synthesis of glucose from certain amino acids, lactate or glycerol), glycogenolysis (the breakdown of glycogen into glucose), and glycogenesis (the formation of glycogen from glucose).

Bacteria in the Digestive System

The large intestine provides a home for trillions of bacteria. Most of these bacteria are helpful. They have several roles in the body. For example, intestinal bacteria:

- Produce vitamins B_{12} and K.
- Control the growth of harmful bacteria.
- Break down poisons in the large intestine.
- Break down some substances in food that cannot be digested, such as fiber and some starches and sugars.

Keeping Your Digestive System Healthy

Most of the time, you probably aren't aware of your digestive system. It works well without causing any problems. However, most people have problems with their digestive system at least once in awhile. Did you ever eat something that didn't "agree" with you? Maybe you had a stomachache or felt sick to your stomach. Maybe you had diarrhea. These could be symptoms of foodborne illness.

Foodborne Illness

Harmful bacteria can enter your digestive system in food and make you sick. This is called **foodborne illness.** The bacteria, or the toxins they produce, may cause vomiting or cramping, in addition to the symptoms mentioned above. You can help prevent foodborne illness by following a few simple rules:

- Keep hot foods hot and cold foods cold. This helps prevent any bacteria in the foods from multiplying.
- Wash your hands before you prepare or eat food. This helps prevent bacteria on your hands from getting on the food.
- Wash your hands after you touch raw foods such as meats, poultry, fish, or eggs. These foods often contain bacteria that your hands could transfer to your mouth.
- Cook meats, poultry, fish, and eggs thoroughly before eating them. The heat of cooking kills any bacteria the foods may contain so they cannot make you sick.

Food Allergies

Food allergies are like other allergies. They occur when the immune system reacts to harmless substances as though they were harmful. Almost 10 percent of children have food allergies. Some of the foods most likely to cause allergies are shown in **Figure** 17.15. Eating foods you are allergic to may cause vomiting, diarrhea, or skin rashes. Some people are very allergic to certain foods. Eating even tiny amounts of the foods causes them to have serious symptoms, such as difficulty breathing. If they eat the foods by accident, they may need emergency medical treatment.

If you think you may have food allergies, a doctor can test you to find out for sure. The tests will identify which foods you are allergic to. Then you can avoid eating these foods. This is the best way to prevent the symptoms of food allergies. To avoid the foods you are allergic to, you may have to read food labels carefully. This is especially likely if you are allergic to common food ingredients, such as soybeans, wheat, or peanuts.

A food intolerance, or food sensitivity, is different to a food allergy. A food intolerance happens when the digestive system is unable to break down a certain type of food. This can result in stomach cramping, diarrhea, tiredness, and weight loss. Food intolerances are often mistakenly called allergies. Lactose intolerance is a food intolerance. A person who is lactose intolerant does not make enough lactase, the enzyme that breaks down the milk sugar lactose. About 75 percent of the world's population is lactose intolerant.

Constipation

Constipation means that a person has three bowel movement or less each week. The stools may also be hard and dry. Sometimes the stools are difficult or painful to pass. The person

Figure 17.15: Some of the foods that commonly cause allergies are shown here. They include nuts, eggs, fish, milk, and shellfish. Are you allergic to any of these foods? (4)

may feel "draggy" and full.

Some people think they should have a bowel movement every day. This is not necessarily true. There is no "right" number of bowel movements. What is normal for one person may not be normal for another. It depends on the foods they eat, how much they exercise, and other factors.

At one time or another, almost everyone has constipation. In most cases, it lasts for a short time and isn't serious. However, constipation can be very uncomfortable. You can follow these tips to help prevent it:

- Eat enough high-fiber foods, including vegetables, fruits, beans, and whole grains.
- Drink plenty of water and other liquids.
- Exercise regularly.
- Don't ignore the urge to have a bowel movement.

Following these tips will help keep your digestive system working properly. It will help you feel good and stay healthy.

Lesson Summary

- The digestive system breaks down food, absorbs nutrients, and gets rid of food wastes.
- Digestive enzymes speed up the reactions of chemical digestion.
- The main organs of the digestive system are the mouth, esophagus, stomach, small intestine, and large intestine.
- Bacteria in the large intestine produce vitamins and have other roles in the body.
- You can follow simple tips to help keep your digestive system healthy.

Review Questions

1. What are three functions of the digestive system?
2. Describe the roles of the mouth in digestion.
3. In which organs of the digestive system does absorption of nutrients take place?
4. Identify two roles of helpful bacteria in the large intestine.
5. List two rules that can help prevent foodborne illness.
6. Explain the role of enzymes in digestion. Give examples to illustrate your answer.
7. Describe peristalsis, and explain why it is necessary for digestion.
8. How can the inner surface area of the small intestine be as big as a basketball court? How does this help the small intestine absorb nutrients?
9. Assume a person has an illness that prevents the large intestine from doing its normal job. Why might the person have diarrhea?
10. Explain why eating high-fiber foods can help prevent constipation.

Further Reading / Supplemental Links

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- http://en.wikipedia.org/wiki/Stomach

Vocabulary

absorption Process in which substances are taken up by the blood; after food is broken down into small nutrient molecules, the molecules are absorbed by the blood.

chemical digestion Digestion in which large food molecules are broken down into small nutrient molecules.

constipation Having three or less bowel movements each week.

digestion Process of breaking down food into nutrients.

digestive system Body system that breaks down food, absorbs nutrients, and gets rid of solid food waste.

duodenum The first part of the small intestine; where most chemical digestion takes place.

elimination The process in which solid food waste passes out of the body.

enzyme A substance, usually a protein, that speeds up chemical reactions in the body.

esophagus The narrow tube that carries food from the throat to the stomach.

food allergies A condition in which the immune system reacts to harmless substances in food as though they were harmful.

foodborne illness An illness caused by harmful bacteria that enter the digestive system in food.

food intolerance Occurs when the digestive system is unable to break down a certain type of food.

ileum The third part of the small intestine; covered with villi; the few remaining nutrients are absorbed in the ileum.

jejunum The second part of the small intestine; where most nutrients are absorbed into the blood; lined with tiny "fingers" called villi.

large intestine The relatively wide tube between the small intestine and anus where excess water is absorbed from food waste.

mechanical digestion Digestion in which large chunks of food are broken down into small pieces.

peristalsis Involuntary muscle contractions which push food through the digestive system.

small intestine The narrow tube between the stomach and large intestine where most chemical digestion and absorption of nutrients take place.

stomach The sac-like organ at the end of the esophagus where proteins are digested.

villi Contain microscopic blood vessels; nutrients are absorbed into the blood through these tiny vessels; located on the jejunum and the ileum.

Points to Consider

- After nutrients are absorbed into the blood, think about how the blood could carry them to all the cells of the body. How does the blood travel? What keeps the blood moving?

Image Sources

(1) HHS. http://www.health.gov/dietaryguidelines/dga2005/healthieryou/images/img_tips_food_label.gif. Public Domain.

(2) http://www.hud.gov/local/ny/news/2005-06-27.cfm
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Chapter 18

Cardiovascular System

18.1 Lesson 18.1: Introduction to the Cardiovascular System

Lesson Objectives

- Identify the main structures of the cardiovascular system.
- Identify three types of blood vessels.
- Describe the differences between the pulmonary and the systemic circulations.
- Identify the main structures of the lymphatic system.
- Outline how the cardiovascular and the lymphatic systems work together.

Check Your Understanding

- What is an organ system?
- What are the three types of muscles found in the human body?

Introduction

Your cardiovascular system has many jobs. It acts as a message delivery service, a pump, a heating system, and a protector of the body against infection. Every cell in your body depends on your cardiovascular system. In this chapter, you will learn how your cardiovascular system works and how it helps to maintain homeostasis.

Functions of the Cardiovascular System

The **cardiovascular system** shown in **Figure** 18.1 is the organ system that is made up of the heart, the blood vessels, and the blood. Your cardiovascular system has many important roles in maintaining homeostasis. It moves nutrients, hormones, gases (such as oxygen) and wastes (such as carbon dioxide) to and from your body cells. It also helps to keep you warm by moving warm blood around your body. To do these tasks, your cardiovascular system works with other body systems such as the respiratory, endocrine, and nervous systems.

The Movement of Gases

It could be said that the movement of gases, especially oxygen and the waste product of cellular respiration, carbon dioxide, is one of the most important aspects of the cardiovascular system. But the cardiovascular system cannot do this alone. It must work with other organ systems, especially the respiratory system (discussed in a later chapter), to move these gases throughout your body.

Oxygen is needed by every cell in your body as it is the final electron acceptor during aerobic cellular respiration. You breath oxygen in and carbon dioxide out through your respiratory system. Once oxygen enters your lungs, it must diffuse into your blood stream for transport around your body.

Oxygen is transported in your blood by attaching to the hemoglobin protein. The oxygen diffuses from the blood into the tissues, while carbon dioxide diffuses in the opposite direction. Carbon dioxide is transported back to the lungs, where it diffuses out of the blood and into your lungs for release from your body.

Parts of the Cardiovascular System

Your heart pushes the blood around your body through the blood vessels. The heart, shown in **Figure** 18.2, is made of cardiac muscle (refer to the *Skin, Bones, and Muscles* chapter). The heart is connected to many blood vessels that bring blood all around the body. The cardiac muscle contracts and pumps blood through the heart and blood vessels.

Blood Vessels

The job of these blood vessels is to channel the blood around the body. There are three main types of blood vessels in the body; arteries, veins, and capillaries.

Arteries are blood vessels that carry blood away from the heart. Arteries have thick walls that have a layer of smooth muscle, as shown in **Figure** 18.3. Arteries usually carry oxygen-rich blood around the body. The blood that is in arteries is under pressure. The contractions

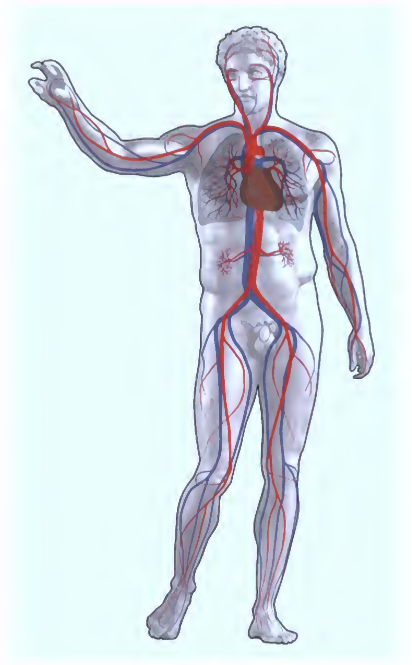

Figure 18.1: The cardiovascular system moves nutrients and other substances through cells. (25)

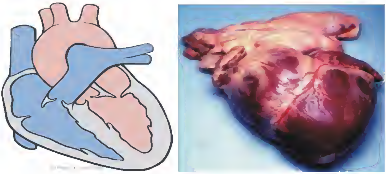

Figure 18.2: Blood is collected in the heart and pumped out to the lungs, where it releases carbon dioxide and picks up oxygen before it is pumped to the rest of the body. (6)

of the heart muscle causes blood to exert force on the walls of the arteries. This force is referred to as *blood pressure*. Blood pressure is highest in the arteries and decreases as the blood moves into smaller blood vessels. Thick walls help prevent arteries from bursting from the pressure of blood.

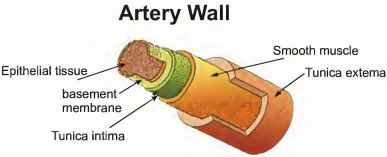

Figure 18.3: Arteries are thick-walled vessels with many layers, including a layer of smooth muscle. (11)

Every cell in the body needs oxygen, but arteries are too large to bring oxygen and nutrients to single cells. Further from the heart, arteries form smaller arteries. These smaller arteries branch into smaller vessels. The smaller blood vessels help to bring nutrients and oxygen and take away waste from body tissues.

The tiniest blood vessels in the body are called **capillaries.** The walls of capillaries are only a single layer of cells thick. Capillaries connect arteries and veins together, as shown in **Figure** 18.4. Capillaries also allow the delivery of water, oxygen and other substances to body cells. They also collect carbon dioxide and other wastes from cells and tissues. Capillaries are so narrow that blood cells must move in single file through them.

A *capillary bed* is the network of capillaries that supply an organ with blood. The more metabolically active a tissue or organ is, the more capillaries it needs to get nutrients and

oxygen.

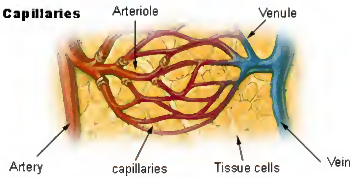

Figure 18.4: Capillaries connect arteries and veins. (1)

Blood is carried back to the heart in blood vessels called **veins.** Veins have thinner walls than arteries do, as you can see in **Figure** 18.5. The blood in veins is not under pressure. Veins have valves that stop blood from moving backward. Blood is moved forward in veins when the surrounding skeletal muscles squeeze the veins. Blood that is carried by veins is usually low in oxygen. The exception is the pulmonary veins that return oxygen-rich blood to the heart from the lungs.

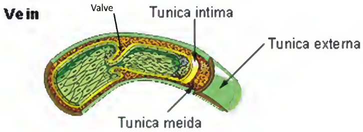

Figure 18.5: The walls of veins are not as thick as artery walls; veins have valves that stop blood from flowing backward. (17)

Blood is a body fluid that is a type of connective tissue. Blood is made of blood cells, and a fluid called **plasma.** The main types of cells found in blood are red blood cells and white blood cells. Red blood cells are the cells that carry oxygen. Oxygen-rich blood is bright red and oxygen-poor blood is dark red. You will learn more about blood in a later lesson in this chapter.

The cardiovascular system of humans is *closed*. That means the blood never leaves the large loop of blood vessels in which it travels. Other animals such as invertebrates have open circulatory systems, in which their blood can leave the blood vessels.

Two Blood Circulation Systems

The blood is pumped around in two large "loops" within the body. One loop moves blood around the body—to the head, limbs, and internal organs. The other loop moves blood to and from the lungs where carbon dioxide is released and oxygen is picked up by the blood. A simple version of these two "loops" is shown in **Figure** 18.6. **Systemic circulation** is the portion of the cardiovascular system which carries oxygen-rich blood away from the heart, to the body, and returns oxygen-poor blood back to the heart. The **pulmonary circulation** is the part of the cardiovascular system which carries oxygen-poor blood away from the heart to the lungs, and returns oxygen-rich blood back to the heart. This oxygen-rich blood then gets pumped around the body in the systemic circulation. These two circulations will be further discussed in Lesson 2.

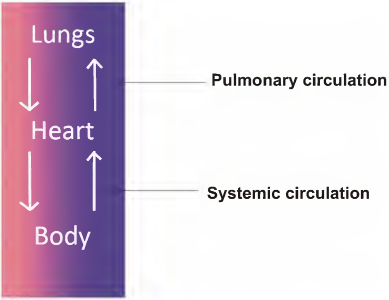

Figure 18.6: The double circulatory system; blood in one circuit has to go through the heart to enter the other circuit. (19)

The Lymphatic System

The **lymphatic system** is a network of vessels and tissues that carry a clear fluid called *lymph*. The lymphatic system, shown in **Figure** 18.7, extends all around the body. Lymph tissues include lymph nodes, lymph ducts, and lymph vessels. Lymph vessels are tube-shaped just like blood vessels. The lymphatic system works with the cardiovascular system to return body fluids to the blood. The lymphatic system and the cardiovascular system are often called the body's two *circulatory systems*.

The lymphatic system has two main jobs:

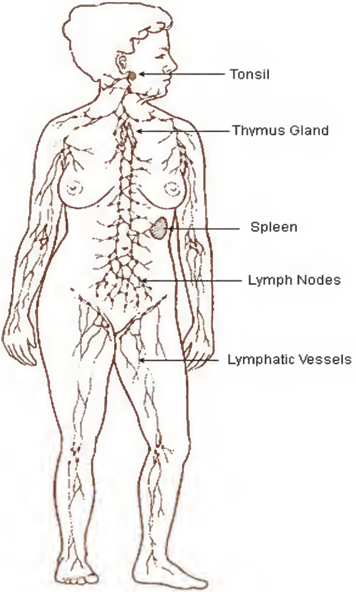

Figure 18.7: The lymphatic system helps return fluid that leaks from the blood vessels back to the cardiovascular system. (5)

- Removing excess fluids from body tissues.
- Making certain types of white blood cells.

Role of the Lymphatic System in Circulation

The lymphatic system collects and returns fluid to the cardiovascular system. A small amount of fluid leaks from the blood vessels when blood is pumped around your body. This fluid collects in the spaces between cells and tissues. Some of the fluid returns to the cardiovascular system, and the rest is collected by the lymph vessels of the lymphatic system, which are shown in **Figure** 18.8.

The fluid that collects in the lymph vessels is called lymph. The lymphatic system then returns the lymph to the cardiovascular system. Unlike the blood system, the lymphatic system is not closed and has no central pump. Lymph moves slowly in lymph vessels. It is moved along in the lymph vessels by the squeezing action of smooth muscles and skeletal muscles.

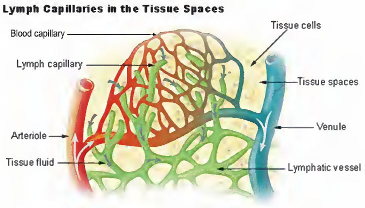

Figure 18.8: Lymph capillaries collect fluid that leaks out from blood capillaries. (3)

Role of the Lymphatic System in the Body's Defenses

The lymphatic system also plays an important role in the immune system. The lymphatic system makes certain blood cells, and also filters, or traps foreign particles. The lymphatic system and contain white blood cells to protect the body from infection.

Organs of the Lymphatic System

Along with the lymph vessels, lymph ducts, and lymph nodes, the lymphatic system also includes many organs. The tonsils, thymus, and spleen, which are shown **Figure** 18.7, each

have a role in the defense of the body against infection. Many of these organs are also part of the immune system.

Tonsils

The tonsils are areas of lymphoid tissue on either side of the throat. The term *tonsils* refers most often to the tonsils in the back of the throat as shown in **Figure** 18.9. But, there are tonsils in the nasal cavity and behind the tongue too. Like other organs of the lymphatic system, the tonsils are also part of the immune system. The immune system help protect the body against infection. The tonsils are believed to help fight off nose and throat and other upper respiratory tract infections such as colds. Tonsils tend to reach their largest size near puberty, after which they get smaller. *Tonsillitis* is an infection of the tonsils that can cause a sore throat and fever.

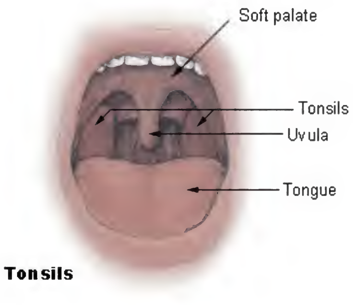

Figure 18.9: The term *tonsils* refers most often to the tonsils in the back of the throat, but there are tonsils in the nasal cavity and behind the tongue too. (9)

Bone Marrow

Bone marrow is the tissue found in the middle of bones. The marrow in the large bones of adults makes new blood cells. Certain white blood cells, called *T-cells,* are made in the bone marrow and move to the thymus to mature. Other white blood cells called *B-cells,* move from the bone marrow to the spleen after they have matured.

Thymus

The thymus is found in the upper chest. Chemicals made by the thymus help the production of certain infection-fighting cells. The thymus is where certain white blood cells called *lymphocytes* mature. These cells move from the bone marrow to the thymus to finish growing. The thymus grows to its largest size near puberty, and gets smaller as a person ages. If a person's thymus is surgically removed or damaged by disease while they are young, the person will be very prone to infections.

Spleen

The spleen is in the abdomen, as shown in **Figure** 18.10. In an area of the spleen called *red pulp*, materials are filtered from the blood, including old and dead red blood cells. The spleen also makes red blood cells. Areas called *white pulp* help fight infections by making white blood cells. If a person's spleen is surgically removed, or does not work properly, the person is prone to certain infections.

You can learn more about the roles of the lymphatic system and white blood cells in the *Diseases and the Body's Defenses* chapter.

Table 18.1: **Structures and Functions of the Cardiovascular and Lymphatic Systems**

System	Structure (organs and tissues)	Function
Lymphatic	Lymph vessels	Transports fluid (lymph) from between body cells back to blood
	Lymph nodes	Traps invading microbes, foreign particles, cancerous cells
	Spleen, tonsils, and adenoids	Traps invading microbes and foreign particles
	Thymus	Site of white blood cell (lymphocyte)maturation
Cardiovascular	Blood vessels	Transports blood around the body
	Blood	Transport of oxygen and nutrients; transports white blood cells to sites of infection and inflammation
	Heart	Pumps blood around the body

Table 18.1: (continued)

System	Structure (organs and tissues)	Function

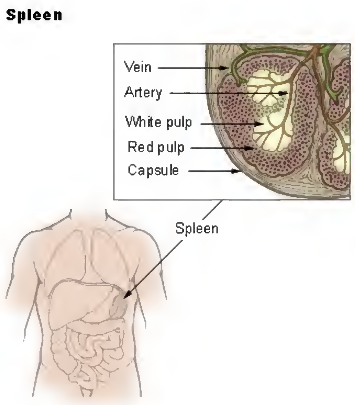

Figure 18.10: In the spleen, the white pulp makes white blood cells, and the red pulp acts like a filter that removes dead and dying cells from the blood. (16)

Lesson Summary

- The cardiovascular system consists of the heart, the blood vessels, and the blood. There are three main types of blood vessels in the body; arteries, veins, and capillaries.
- The systemic circulation is the portion of the cardiovascular system, which carries oxygen-rich blood away from the heart, to the body, and returns oxygen-poor blood back to the heart. The pulmonary circulation is the part of the cardiovascular system, which carries oxygen-poor blood away from the heart to the lungs, and returns oxygen-rich blood back to the heart.

- Lymph tissues include lymph nodes, lymph ducts, and lymph vessels. Organs of the lymphatic system include the tonsils, thymus, and spleen. The lymphatic system works with the cardiovascular system to return body fluids to the blood. The two systems together are often called the body's two *circulatory systems*.

Review Questions

1. Identify the main structures of the cardiovascular system.
2. Identify three types of blood vessels found in the body.
3. Which blood vessels bring blood away from the heart?
4. What are the smallest blood vessels in the body called?
5. What blood vessels bring blood back to the heart?
6. Where does blood in the pulmonary system go once it leaves the heart?
7. Where does blood in the systemic circulation go once it leaves the heart?
8. What does blood that leaves the heart in the systemic circulation have that body cells need?
9. Identify the main tissues and organs of the lymphatic system.
10. Outline how the cardiovascular and the lymphatic systems work together.
11. What is lymph, and where does it come from?
12. Identify one function of tonsils.
13. What might happen if a person did not have a spleen?
14. Name the two circulatory systems of the body.

Further Reading / Supplemental Links

- http://en.wikipedia.org/wiki/Heart

Vocabulary

arteries Blood vessels that carry blood away from the heart.

blood A body fluid that is a type of connective tissue; moves oxygen and other compounds throughout the body.

capillaries The smallest and narrowest blood vessels in the body.

cardiovascular system The organ system that is made up of the heart, the blood vessels, and the blood.

lymphatic system A network of vessels and tissues that carry a clear fluid called *lymph;* includes lymph nodes, lymph ducts, and lymph vessels.

plasma The straw-colored fluid in blood.

pulmonary circulation The part of the cardiovascular system which carries oxygen-poor blood away from the heart to the lungs, and returns oxygen-rich blood back to the heart.

systemic circulation The portion of the cardiovascular system which carries oxygen-rich blood away from the heart to the body, and returns oxygen-poor blood back to the heart.

veins Blood vessels that carry blood back to the heart.

Points to Consider

- Consider how the structure of the heart helps to maintain the systemic and pulmonary circulations.
- Consider how problems with the coronary circulation can affect the entire body.
- How would a hole in the heart muscle that allowed blood in the two ventricles to mix affect the rest of the body?

18.2 Lesson 18.2: Heart and Blood Vessels

Lesson Objectives

- Describe the structure of the heart.
- Outline how blood moves through the heart.
- Describe the importance of valves in the heart.
- Describe the coronary circulation.

Check Your Understanding

- What is the role of the cardiovascular system?
- What is the main function of the heart?

Introduction

The heart is divided into four chambers, the left and right *atria* and the left and right *ventricles*. An **atrium** is one of the two small, thin-walled chambers on the top of the heart

that blood first enters. A **ventricle** is one of the two muscular V-shaped chambers that pump blood out of the heart. The four chambers of the heart are shown in **Figure** 18.11. The atria receive the blood, and the ventricles pump the blood out of the heart. Each of the four chambers of the heart have a specific job, these are:

- The right atrium receives oxygen-poor blood from the body.
- The right ventricle pumps oxygen-poor blood toward the lungs.
- The left atrium receives oxygen-rich blood from the lungs.
- The left ventricle pumps oxygen-rich blood out of the heart to the rest of the body.

The heart is usually found in the left to middle of the chest with the largest part of the heart slightly to the left. The heart is usually felt to be on the left side because the left ventricle is bigger and stronger than the right ventricle. The heart is surrounded by the lungs.

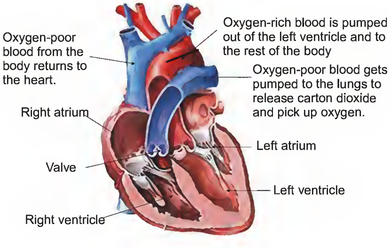

Figure 18.11: The atria receive blood and the ventricles pump blood out of the heart. (18)

Blood Flow Through the Heart

Blood flows through the heart in two separate loops; you could think of them as a "left side loop" and a "right side loop". The *right side* and *left side* of the heart refer to your heart as it sits inside your chest. Its left side is your left side and, its right side is your right side.

The right side of the heart collects deoxygenated blood from the body and pumps it into the lungs where it releases carbon dioxide and picks up oxygen. The left-side carries the oxygenated blood back from the lungs, into the left side of the heart which then pumps the oxygenated blood throughout the rest of the body.

The Heartbeat

To move blood through the heart, the cardiac muscle needs to contract in an organized way. Blood first enters the atria, as shown in **Figure** 18.12. When the atria contract blood is pushed into the ventricles. After the ventricles fill with blood, they contract and blood is pushed out of the heart. Valves in the heart keep the blood flowing in one direction. You can see some of the valves in **Figure** 18.12. The valves do this by opening and closing in one direction only. Blood moves only forward through the heart. The valves stop the blood from flowing backward. There are four valves of the heart:

- The two *atrioventricular (AV) valves* stop blood from moving from the ventricles to the atria.
- The two *semilunar (SL) valves* are found in the arteries leaving the heart, and they prevent blood flowing back from the arteries into the ventricles.

The "lub-dub" sound of the heartbeat is caused by the closing of the AV valves (lub), and SL valves (dub), after blood has passed through them.

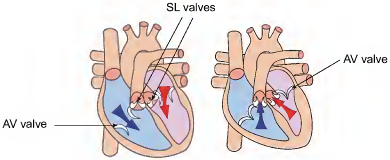

Figure 18.12: Blood flows in only one direction in the heart; blood enters the atria, contracting and pushing blood into the ventricles, the atria relax, the ventricles fill with blood, contract, and push blood around the body. (21)

Control of the Heartbeat

The heart is a made up of cardiac muscle cells. Cardiac cells are able to contract by themselves. They do not need help from the nervous system. This is different than skeletal muscle, which needs messages from nerve to contract. But the contractions of cardiac muscle still need to be coordinated to make sure the cells contract as a group.

The contraction rate of cardiac muscle is controlled by two small groups of cardiac muscle cells called the *sinoatrial (SA)* and *atrioventricular (AV) nodes*. The SA node is found in the wall of the right atrium. It starts the contraction of muscle cells in the atria. The contracting

cells send electrical messages called *impulses* to other muscle cells. The impulses then reach the AV node. The AV node is found in the lower part of the right atrium. The AV node conducts the impulses that come from the SA node through the atria to the ventricles. The impulses then spread around the ventricles and they contract.

The frequency of the heart's contractions, called the *heart rate,* can be changed by nervous or hormonal signals. Activities such as exercise or getting frightened can make the heart rate increase. After the exercise is over, or the fright has passed, the heart rate returns to normal.

Blood Circulation and Blood Vessels

There are actually two separate circulation systems within the heart. Both of these together make up the complete circulatory system of humans and other animals. Neither system can work alone. These are the **pulmonary circulation** and the **systemic circulation.** The human heart is made up of two separate pumps, the right side which pumps deoxygenated blood into the pulmonary circulation, and the left side which pumps oxygenated blood into the systemic circulation. Blood in one circuit has to go through the heart to enter the other circuit.

The blood vessels are an important part of the cardiovascular system. They connect the heart (the pump), to every cell in the body. Arteries carry blood away from the heart, while veins return blood to the heart. The main arteries and veins of the heart are shown in **Figure** 18.13.

The veins that return oxygen- poor blood to the heart are the *superior vena cava* and the *inferior vena cava.* The *pulmonary veins* return oxygen-rich blood to the heart. The *pulmonary veins* are the only veins that carry oxygen-rich blood all other veins carry oxygen-poor blood.

The *pulmonary arteries* carry oxygen-poor blood away from the heart to the lungs. These are the only arteries that carry oxygen-poor blood. The aorta is the largest artery in the body. It carries oxygen-rich blood away from the heart. Further away from the heart, the aorta branches into smaller arteries.

Pulmonary Circulation

The **pulmonary circulation** is the part of the cardiovascular system which carries oxygen-poor blood away from the heart and brings it to the lungs. Oxygen-poor blood returns to the heart from the body and leaves the right ventricle through the pulmonary arteries, which carry the blood to each lung. Once at the lungs, the red blood cells release carbon dioxide and pick up oxygen during *respiration.* The oxygen-rich blood then leaves the lungs through the pulmonary veins which return it to the left side of the heart. This completes

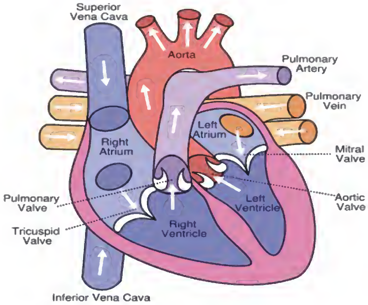

Figure 18.13: The right side of the heart pumps deoxygenated blood into the pulmonary circulation; the left side pumps oxygenated blood into the systemic circulation. (7)

the *pulmonary cycle*.

The oxygenated blood is then pumped to the body through the systemic circulation before returning again to the pulmonary circulation.

Systemic Circulation

The **systemic circulation** is the part of the cardiovascular system which carries oxygen-rich blood away from the heart, to the body, and returns oxygen-poor blood back to the heart. Oxygen-rich blood leaves the left ventricle through the aorta, from where it goes to the body's organs and tissues. The blood vessels that supply oxygen and nutrients to organs and tissues are much smaller than the vessels that leave the heart. Recall that capillaries are the smallest blood vessels. The tissues and organs absorb the oxygen, through the capillaries. Oxygen-poor blood is collected from the tissues and organs by tiny veins, which then flow into bigger veins. The inferior and superior venae cavae, are the large veins that return oxygen-poor blood to the right side of the heart. This completes the systemic cycle. The blood released carbon dioxide and gets more oxygen in the pulmonary circulation before returning to the systemic circulation.

Coronary Circulation

Just like every other organ in the body, the heart needs its own blood supply. It gets this blood in the **coronary circulation.** Although blood fills the chambers of the heart, the heart muscle tissue is so thick that it needs its own blood vessels to deliver oxygen and nutrients into the muscle. The coronary circulation is part of the systemic circulation. The vessels that deliver oxygen-rich blood to the heart muscle are called *coronary arteries*. The coronary arteries branch directly from the aorta, just above the heart, as shown in **Figure** 18.14. The vessels that remove the deoxygenated blood from the heart muscle are known as *cardiac veins*. Problems with the coronary circulation are often referred to as *heart disease*.

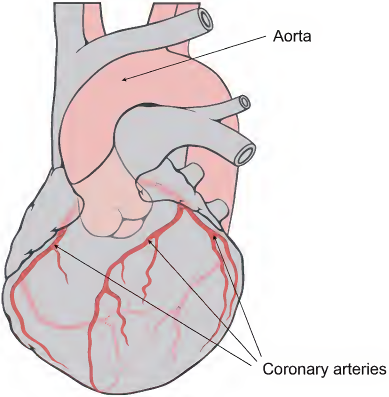

Figure 18.14: In coronary circulation, the arteries that bring oxygen to the cardiac cells branch off the aorta; heart attacks are caused by blockages of the coronary arteries and blockages in the coronary arteries stop oxygen from getting to the heart muscle. (8)

The circulation of blood around the body has been studied by people for a long time. The roles of the organs of the circulatory system were a mystery for many hundreds of years. For example, it was once believed that the left ventricle and arteries were filled with air, and the liver made blood. The pulmonary circulation was first discovered by a Syrian physician, Ibn al-Nafis, in 1242. Ibn al-Nafis was the first person to describe the coronary circulation. However, credit for the first description of blood circulation is given to an English physician

William Harvey. In 1616, Harvey first described the pulmonary and systemic circulation systems in detail.

Lesson Summary

- The heart is divided into four chambers, the left and right *atria* and the left and right *ventricles*. The right side of the heart collects deoxygenated blood from the body and pumps it into the lungs where it releases carbon dioxide and picks up oxygen. The left-side carries the oxygenated blood back from the lungs, into the left side of the heart which then pumps the oxygenated blood throughout the rest of the body.
- The valves in the heart prevent blood from flowing backward into the heart. The contraction rate of cardiac muscle is controlled by two small groups of cardiac muscle cells called the *sinoatrial* (SA) and *atrioventricular* (AV) nodes.
- The heart has its own blood supply, which is called the coronary circulation. The heart is fed oxygen-rich blood by coronary arteries. Oxygen-poor blood is collected by coronary veins.

Further Reading / Supplemental Links

- http://en.wikipedia.org/wiki/William_Harvey
- http://thevirtualheart.org/anatomyindex.html
- http://en.wikipedia.org/wiki/Cardiac_cycle

Review Questions

1. Name the four chambers of the heart.
2. Where does oxygen-poor blood first enter the heart?
3. Do ventricles pump blood out of the heart or do they pump blood into the atria?
4. What is the purpose of the valves in the heart?
5. What do the AV valves do?
6. Does the vena cava carry oxygen-poor or oxygen-rich blood?
7. Why can the heart be considered to be two separate pumps?
8. How might a hole in the heart wall between the two ventricles affect the circulation of blood?
9. To what organ or organs does the coronary circulation bring blood?
10. To what organ or organs does the pulmonary circulation bring blood?

Vocabulary

atrioventricular (AV) valves Valves that stop blood from moving from the ventricles back into the atria.

atrium One of the two small, thin-walled chambers on the top of the heart that blood first enters.

coronary circulation The blood supply that feeds the heart.

semilunar (SL) valves Found in the arteries leaving the heart; prevents blood flowing back from the arteries into the ventricles.

ventricle One of the two muscular V-shaped chambers that pump blood out of the heart.

Points to Consider

- Identify how the different components of the blood have very different roles in the cardiovascular system.
- Consider how diet can affect the oxygen-carrying ability of blood.

18.3 Lesson 18.3: Blood

Lesson Objectives

- List the components of blood.
- Identify three functions of blood.
- Name the oxygen-carrying protein found in red blood cells.
- Identify the main function of white blood cells.
- Describe the importance of the ABO blood system.
- Identify three blood disorders or diseases.

Check Your Understanding

- What is the main function of the blood?
- What is the role of oxygen in aerobic (cellular) respiration?

Introduction

Did you know that blood is a tissue? Blood is a fluid connective tissue that is made up of red blood cells, white blood cells, platelets, and plasma. It moves around the body through the blood vessels by the pumping action of the heart. Oxygen rich blood carried in arteries brings oxygen and nutrient to all the body's cells. Oxygen-poor blood carries carbon dioxide and other metabolic wastes away from the cells. As well as the transport of gases, nutrients, and wastes, blood has many other functions that are important to homeostasis. You will learn more about these functions in this lesson.

Components of Blood

Blood is a colloidal solution. A colloidal solution it is made up of particles that are suspended in a fluid. The cells in blood are suspended in plasma, the liquid part of blood. The cells that make up the blood are shown in **Figure** 18.15. The different components of blood have different roles. Some of the roles of blood include:

- The defense of the body against infection by microorganisms or parasites.
- The transport of chemical messages, such as hormones and hormone-like substances.
- The control of body temperature.
- The repair of damage to body tissues.

Plasma

If you were to filter out all the cells in blood, plasma is what would be left over. **Plasma** is the golden-yellow liquid part of the blood. Plasma is about 90 percent water and about 10 percent dissolved proteins, glucose, ions, hormones, and gases. Blood is made up of mostly plasma. The blood cells make up the rest of the volume.

Red Blood Cells

Red blood cells (RBCs) are flattened disk-shaped cells that carry oxygen. They are the most common blood cell in the blood. There are about 4 to 6 million RBCs per cubic millimeter of blood. Each RBC has 200 million molecules of hemoglobin. Hemoglobin is the protein that carries oxygen. Hemoglobin also gives the RBCs their red color. Red blood cells are made in the red marrow of long bones, ribs, skull, and vertebrae. Each red blood cell lives for only 120 days (about three months). After this time, they are destroyed in liver and spleen. Red blood cells are shown in **Figure** 18.16. Mature RBCs do not have a nucleus or other organelles.

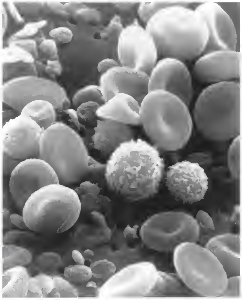

Figure 18.15: A scanning electron microscope (SEM) image of human blood cells; red blood cells are the flat, bowl-shaped cells, the tiny disc-shaped pieces are platelets and white blood cells are the round cells visible in the center. (10)

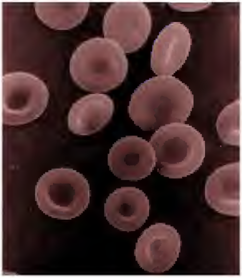

Figure 18.16: The flattened shape of RBCs helps them to carry more oxygen than if they were rounded. (13)

White Blood Cells

White blood cells (WBCs) are usually larger than red blood cells. They have a nucleus but do not have hemoglobin. White blood cells make up less than one percent of the blood's volume. Most WBCs are made in the bone marrow, some mature in the lymphatic system. WBCs defend the body against infection by bacteria, viruses and other pathogens. Each WBC type has a specific defense job. Three of the most common white blood cells in the body are listed here.

- *Neutrophils* can squeeze through capillary walls and swallow particles such as bacteria and parasites.
- *Macrophages* can also swallow and destroy old and dying cells, bacteria, or viruses. In **Figure** 18.17 a macrophage is attacking and swallowing two particles, possibly pathogens. Macrophages also release chemical messages that cause the number of WBC to increase.
- *Lymphocytes* fight infections by viruses and bacteria. Some lymphocytes attack and kill cancer cells. Other lymphocytes attack cells that are infected by viruses. Lymphocytes called B-cells make antibodies. **Antibodies** are chemicals that identify pathogens or other substances as being harmful, or they can destroy the pathogen. To learn more about the role of WBCs in protecting the body from infection, go to the *Diseases and the Body's Defenses* chapter.

Figure 18.17: A type of WBC, called a macrophage, is attacking and about to swallow two particles. (23)

Platelets

Platelets are very small, but they are very important in blood clotting. Platelets are not cells they are sticky little pieces of larger cells. They bud off large cells that stay in the bone marrow. A platelet sits between a RBC and a WBC in **Figure** 18.18. Platelets carry chemicals that are important for proper blood clotting. When a blood vessel gets cut, platelets stick to the injured areas. They release chemicals called *clotting factors* which cause a web of protein fibers to form. This web catches RBCs and forms a clot. This clot stops more blood from leaving the body through the cut blood vessel. The clot also stops bacteria from entering the body.Platelets survive in the blood for 10 days before they are removed by the liver and spleen.

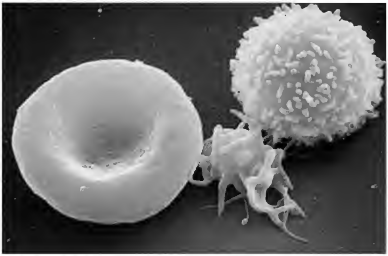

Figure 18.18: A platelet lies between a RBC, at left, and a WBC at right; platelets are little pieces of larger cells, called *megakaryocytes,* which are found in the bone marrow. (20)

Transport of Chemical Messages

The blood also acts as a messenger delivery service. Chemical messages called *hormones* are carried and delivered by the blood to cells around the body. Hormones are released into the blood by the cells that make them and are delivered by the blood to the cells the hormones are made for. An example of a hormone transported in the blood is insulin, which regulates the concentration of glucose in the blood.

Control of Body Temperature

Your blood system does more than deliver oxygen and nutrients to your body cells. Your blood also moves heat (thermal energy) around your body. When your brain senses that

your body temperature is increasing, it sends messages to the blood vessels in the skin to increase in diameter. Increasing the diameter of the blood vessels increases the amount of blood and heat that moves near the skin surface. The heat is then released from the skin.

Blood Clotting

Blood clotting is a complex process by which blood forms solid clots. As discussed above, clotting is important to stop bleeding and begin repair of damaged blood vessels. Blood clotting disorders can lead to an increased risk of bleeding or clotting inside a blood vessel. Platelets are important for the proper clotting of blood.

Clotting is started almost immediately when an injury damages the inside lining of a blood vessel. Platelets clump together, forming a plug at the site of injury. Then, proteins in the plasma cause a series of chemical reactions that form a tough protein called **fibrin.** The fibrin strands form a web across the platelet plug, trapping red blood cells before they can leave through the wound site. This mass of platelets, fibrin, and red blood cells forms a clot that hardens into a scab.

Certain nutrients are needed for the clotting system to work properly. Two of these are calcium and vitamin K. Bacteria that live in your intestines make enough vitamin K so you do not need to eat extra vitamin K in your food.

Blood Types

Blood type is determined by the presence or absence of certain molecules, called *antigens,* on the surface of red blood cells (RBCs). There are four blood types; A, B, AB, and O.

Type A blood has type A antigens on the RBCs in the blood.

Type AB blood has A and B antigens on the RBCs.

Type B has B antigens on the RBCs.

Type O does not have any antigens (neither A nor B).

The blood types may also have antibodies for other blood types in their plasma. For example, a person with type A blood may have anti-B antibodies (against B antigens), and a person with type O blood can have anti-A and anti-B antibodies in their blood. The blood type of a person can be worked out by testing a drop of a person's blood using anti-A or anti-B antibodies.

The ABO blood group system is most important if a person needs a blood transfusion. A **blood transfusion** is the process of putting blood or blood products from one person into the circulatory system of another person.

If a person with type O blood received type A blood, the anti-A antibodies in the person's

blood would attack the A antigens on the RBCs in the donor blood, as shown in **Figure** 18.19. The antibodies would cause the RBCs to clump together, and the clumps could block a blood vessel. Such a reaction could be fatal.

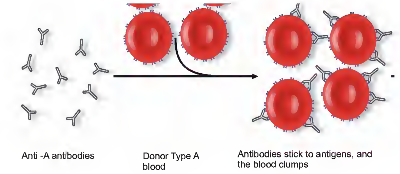

Figure 18.19: A person with type O blood has A and B antibodies in their plasma; if the person was to get type A blood instead of type O, Their A antibodies would attach to the antigens on the RBCs and cause them to clump together. (14)

The Rhesus System

The second most important blood group system in human blood is the Rhesus (Rh) system. The Rh blood group system currently consists of 50 blood group antigens, including the 5 antigens D, C, c, E, and e. The commonly used terms Rh factor, Rh positive and Rh negative refer to the D antigen only. A person either has, or does not have the Rh(D) antigen on the surface of their RBCs; written as *Rh(D) positive* (does have the RhD antigen) or *Rh(D) negative* (does not have the antigen).

Blood Donors

Recall that people with type O blood do not have any antigens on their RBCs. As a result, type O blood can be given to people with blood types A, B, or AB. If there are no antigens on the RBCs, there cannot be an antibody reaction to the blood. People with type O blood are often called **universal donors.**

The blood plasma of AB blood does not contain any anti-A or anti-B antibodies. People with type AB blood can receive any ABO blood type. People with type AB positive blood are called **universal recipients.** The antigens and antibodies that define blood type are listed in **Table** (18.2).

In April 2007 researchers discovered a way to convert blood types A, B, and AB to O. The researchers used enzymes to remove the antigens on the surface of the RBCs. This discovery could lead to producing or modifying blood cells that can be used as donors to people with all blood types.

Table 18.2: **Blood Types, Antigens, and Antibodies**

Blood type	Antigen type	Plasma antibodies	Can receive blood from types	Can donate blood to types
A	A	anti-B	A,O	A, AB
B	B	anti-A	B,O	B, AB
AB	A and B	none	AB, A, B, O	AB
O	none	anti-A, anti-B	O	AB, A, B, O

(*Source:* Niamh Gray-Wilson)

Blood Diseases

Problems can occur with red blood cells, white blood cells, platelets, and other parts of the blood. Many blood disorders are genetic, they are inherited from a parent. Some blood diseases are a caused by not getting enough of a certain nutrient, while others are cancers of the blood.

Sickle-Cell Disease

Sickle cell disease is a blood disease that is caused by abnormally-shaped blood protein hemoglobin. Many of the RBCs of a person with sickle cell disease are long and curved (sickle-shaped), as shown in **Figure** 18.20. The long, sickle-shaped RBCs can have damaged cell membranes, which can cause them to burst. The long shape of the cells can cause them to get stuck in narrow blood vessels. This clotting causes oxygen starvation in tissues, which causes pain and may cause damage such as stroke or heart attack. People with sickle-cell disease are most often well, but can on occasion have painful attacks. The disease is not curable, but can be treated with medicines. Heterozygous individuals have an advantage; they are resistant to severe malaria. See the *Genetics* chapter for further discussion.

Anemia

Hemoglobin is the oxygen-carrying molecule found inside RBCs. **Anemia** results when there is not enough hemoglobin in the blood to carry oxygen to body cells. Hemoglobin normally carries oxygen from the lungs to the tissues. Anemia leads to a lack of oxygen in organs. Anemia is usually caused by one of three things:

- A loss of blood volume through a bleeding wound or a slow leak of blood.
- The destruction of RBCs.

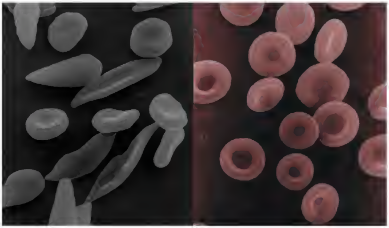

Figure 18.20: The RBCs of a person with sickle cell disease (left) are long and pointed rather than straight like normal cells (right); the abnormal cells cannot carry oxygen properly and can get stuck in capillaries. (15)

- Lack of RBC production.

Anemia may not have any symptoms. Some people with anemia feel weak or tired in general or during exercise. They also may have poor concentration. People with more severe anemia often get short of breath during activity. **Iron-deficiency anemia** is the most common type of anemia. It occurs when the dietary intake or absorption of iron is less than what is needed by the body. As a result, hemoglobin, which contains iron, cannot be made. In the United States, 20 percent of all women of childbearing age have iron deficiency anemia, compared with only 2 percent of adult men. The most common cause of iron deficiency anemia in young women is blood lost during menstruation. Iron deficiency anemia can be avoided by getting the recommended amount of iron in the diet. Anemia is often treated or prevented by taking iron supplements.

Boys and girls aged between the ages of 9 and 13 should get 9 mg of iron every day. Girls between the ages of 14 and 18 should get 15 mg of iron every day. Boys aged between the ages of 14 and 18 should get 11 mg of iron every day. Pregnant women need the most iron—27 mg daily.

Good sources of iron include shellfish such as clams and oysters. Red meat such as beef is also a good source of iron. Non-animal sources of iron include seeds, nuts, and legumes. Breakfast cereals often have iron added to them in a process called *fortification*. Some good sources of iron are listed in **Table** (18.3). Eating vitamin C along with the iron-containing food increases the amount of iron that the body can absorb.

Table 18.3:

Food	Milligrams (mg) of Iron
Canned clams, drained, 3 oz	23.8
Fortified dry cereals, about 1 oz	1.8 to 21.1
Roasted pumpkin and squash seeds, 1 oz	4.2
Cooked lentils, ½ cup	3.3
Cooked fresh spinach, ½ cup	3.2
Cooked ground beef, 3 oz	2.2
Cooked sirloin beef, 3 oz	2.0

(*Created by:* Niamh Gray-Wilson. *Information Source:* Centers of Disease Control and Prevention http://www.cdc.gov/nccdphp/dnpa/nutrition/nutrition_for_everyone/iron_deficiency/#Iron%20Sources)

Leukemia

Leukemia is a cancer of the blood or bone marrow. It is characterized by an abnormal production of blood cells, usually white blood cells. **Lymphoma** is a type of cancer in white blood cells called *lymphocytes*. There are many types of lymphoma.

Hemophilia

Hemophilia is the name of a group of sex-linked (X-linked) hereditary diseases that affect the body's ability to control blood clotting (see the *Genetics* chapter). Hemophilia is caused by a lack of clotting factors in the blood. Clotting factors are needed for the normal clotting of blood. A person who has hemophilia is initially able to make a clot to stop the bleeding, but because fibrin is not produced, the body is unable to keep a clot at an injury site. The risk of internal bleeding is also increased in hemophilia, especially into muscles, joints, or bleeding into closed spaces.

Lesson Summary

- Blood is a colloidal solution that contains red blood cells, white blood cells, and platelets. The cells are suspended in plasma. The red blood cells give blood its red color. Blood carries oxygen and nutrients to body calls and carries wastes away. It also helps to maintain body temperature and to carry chemical messages called *hormones* around the body.
- Hemoglobin is the oxygen-carrying protein that is found in red blood cells. White blood cells defend the body against infection by bacteria, viruses and other pathogens.

Some WBCs swallow pathogens, and others produce antibodies that attack and destroy pathogens.
- Blood type is determined by the presence or absence of certain molecules, called *antigens,* on the surface of red blood cells (RBCs). There are four blood types; A, B, AB, and O.
- If a person receives the wrong blood type, antibodies in the person's blood would attack the antigens on the RBCs in the donor blood. The antibodies would cause the RBCs to clump together, and the clumps could block a blood vessel.
- Sickle cell disease is a blood disease that is caused by abnormally-shaped blood protein hemoglobin.
- Anemia is a disorder in which there is not enough hemoglobin in the blood to carry oxygen to body cells.

Review Questions

1. What types of cells are found in blood?
2. What is the liquid part of blood called?
3. What is the function of platelets?
4. Identify two functions of blood other than bringing oxygen to body cells.
5. What is the oxygen-carrying protein found in red blood cells?
6. Identify two ways that white blood cells defend the body from infection.
7. How are the red blood cells of the different blood groups different?
8. They have different antigens on the surface of the cells.
9. Why are people with type O blood called *universal donors?*
10. Why are people with type AB blood called *universal recipients?*
11. Problem | question=Identify three blood disorders or diseases. |difficulty=Beginning | solution= Problem | question=How can the shape of the hemoglobin protein in a person with sickle-cell disease affect other body systems? |difficulty=Challenging | solution=
12. What is a common cause of anemia in young people?
13. Identify two good sources of iron in the diet.

Further Reading / Supplemental Links

- http://en.wikipedia.org/wiki

Vocabulary

ABO blood type system Blood group system that is determined by the presence or absence of certain molecules, called antigens, on the surface of red blood cells (RBCs); there are four blood types in the ABO system: A, B, AB, and O.

anemia The condition of not having enough hemoglobin in the blood to carry oxygen to body cells.

antibodies Proteins that identify pathogens or other substances as being harmful; flow in blood; can destroy pathogens by attaching to the cell membrane of the pathogen.

blood clotting The complex process by which blood forms solid clots.

blood transfusion The process of putting blood or blood products from one person into the circulatory system of another person.

fibrin A tough protein that forms strands during the blood clotting process.

hemophilia A group of hereditary diseases that affect the body's ability to control blood clotting.

iron-deficiency anemia Occurs when the dietary intake or absorption of iron is less than what is needed by the body. As a result, hemoglobin, which contains iron, cannot be made.

leukemia Cancer of the blood or bone marrow; characterized by an abnormal production of blood cells, usually white blood cells.

lymphoma Cancer of white blood cells called *lymphocytes*.

plasma The golden-yellow liquid part of the blood.

platelets Fragments of larger cells that are important in blood clotting.

red blood cells (RBCs) Flattened disk-shaped cells that carry oxygen, the most common blood cell in the blood. Mature red blood cells do not have a nucleus.

rhesus (Rh) system The second most important blood group system in human blood transfusion. A person either has, or does not have the Rh(D) antigen on the surface of their RBCs; written as *Rh(D) positive* (does have the RhD antigen) or *Rh(D) negative* (does not have the antigen).

sickle cell disease A blood disease that is caused by abnormally-shaped blood protein hemoglobin.

universal donor A person with type O positive blood; type O RBC do not have any antigens on their membranes and so would not cause an immune reaction in the body of a recipient.

universal recipient A person with type AB positive blood; the blood plasma of AB blood does not contain any anti-A or anti-B antibodies. People with type AB blood can receive any ABO blood type.

white blood cells Nucleated blood cells that are usually larger than red blood cells; defend the body against infection by bacteria, viruses, and other pathogens.

Points to Consider

- Why is the blood in veins not under pressure?
- How can your diet affect the cardiovascular system?

18.4 Lesson 18.4: Health of the Cardiovascular System

Lesson Objectives

- Outline the cause of blood pressure in arteries.
- Identify the healthy range for blood pressure.
- Describe three types of cardiovascular disease.
- Identify things you can do to avoid cardiovascular disease.

Check Your Understanding

- What is the role of the cardiovascular system?

Introduction

The health of your whole body depends on the good health of your cardiovascular system. The health of the cardiovascular system (CV system) can be overlooked because damage to the CV system often does not have any symptoms. In this lesson you will learn about common health problems with the CV system, and how you can work toward having a healthy CV system.

Blood Vessels and Blood Pressure

Blood pressure is the force exerted by circulating blood on the walls of blood vessels. The contracting ventricles push blood out of the heart under force. The force of the contractions put the blood under pressure. The pressure causes the walls of the arteries to move in a rhythmic fashion. Blood in arteries is under the greatest amount of pressure. A person's pulse is the throbbing of their arteries that results from the heart beat.

The pressure of the circulating blood gradually decreases as blood moves from the arteries, and into the smaller blood vessels. Blood that is in veins is not under pressure. The term *blood pressure* generally refers to the pressure in the larger arteries that take blood away from the heart. Arterial pressure results from the force that is applied to blood by the contracting heart, where the blood "presses" against the walls of the arteries.

The *systolic* arterial pressure is the highest pressure in the arteries. The *diastolic* arterial pressure is the lowest pressure. Arterial pressure is most commonly measured by an instrument called a *sphygmomanometer,* shown in **Figure** 18.21. The height of a column of mercury indicates the pressure of the circulating blood. Many modern blood pressure devices no longer use mercury, but values are still reported in millimeters of mercury (mm Hg).

Figure 18.21: A digital sphygmomanometer is made of an inflatable cuff and a pressure meter to measure blood pressure. (22)

Healthy Blood Pressure Ranges

In the United States, the healthy ranges for arterial pressure are:

- Systolic: less than 120 mm Hg
- Diastolic: less than 80 mm Hg

Blood pressure is usually written as systolic/diastolic mm Hg. For example, a reading of 120/80 mm Hg, is said as "one twenty over eighty." These measures of arterial pressure are not static, they change with each heartbeat and during the day. Factors such as age, gender and race also influence blood pressure values. Pressure also varies with exercise, emotions, sleep, stress, nutrition, drugs, or disease.

Studies have shown that people whose systolic pressure is around 115 mm Hg rather than 120 mm Hg have fewer health problems. Clinical trials have shown that people who have arterial pressures at the low end of these ranges have much better long term cardiovascular health.

Hypertension which is also called *high blood pressure,* is a condition in which a person's blood pressure is always high. Hypertension is said to be present when a person's systolic blood pressure is always 140 mm Hg or higher, and/or their diastolic blood pressure is always 90 mm Hg or higher. Having hypertension increases a person's chance for developing heart disease, having a stroke, and other serious cardiovascular diseases.

Hypertension often does not have any symptoms, so a person may not know they have high blood pressure. For this reason hypertension is often called the silent killer. However, hypertension can be easily diagnosed and is usually treatable. Treatments for hypertension include diet changes, exercise, and medication.

Atherosclerosis and Other Cardiovascular Diseases

A **cardiovascular disease (CVD)** is any disease that affects the cardiovascular system. But, the term is usually used to describe diseases that are linked to atherosclerosis. **Atherosclerosis** is a chronic inflammation of the walls of arteries that causes swelling and a buildup of material called **plaque.** Plaque is made of cell pieces, fatty substances, calcium, and connective tissue that build up around the area of inflammation. As a plaque grows it stiffens and narrows the artery, which reduces the flow of blood through the artery, shown in **Figure** 18.22.

Atherosclerosis

Atherosclerosis normally begins in later childhood, and is usually found in most major arteries. It does not usually have any early symptoms. Causes of atherosclerosis include a high-fat diet, high cholesterol, smoking, obesity, and diabetes. Atherosclerosis becomes a threat to health when the plaque buildup interferes with the blood circulation in the heart or the brain. A blockage in the blood vessels of the heart can cause a *heart attack.* Blockage of the

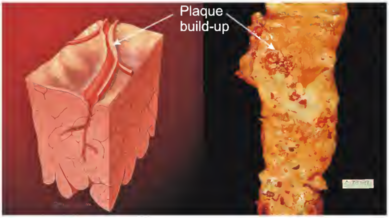

Figure 18.22: Atherosclerosis is sometimes referred to as *hardening* of the arteries; plaque build-up reduces the blood flow through the artery. (24)

circulation in the brain can cause a *stroke*. According to the American Heart Association, atherosclerosis is a leading cause of CVD.

Coronary Heart Disease

Cardiac muscle cells are fed by the coronary arteries. Blocked flow in a coronary artery can result in a lack of oxygen and the death of heart muscle. **Coronary heart disease** is the end result of the buildup of plaques within the walls of the coronary arteries. Coronary heart disease often does not have any symptoms. A symptom of coronary heart disease is chest pain. Occasional chest pain, called *angina* can happen during times of stress or physical activity. The pain of angina means the heart muscle fibers need more oxygen than they are getting.

Most people with coronary heart disease often have no symptoms for many years until they have a heart attack. **A heart attack** happens when the blood supply to a part of the heart is blocked. The cardiac muscle that depends on the blood supply from the blocked artery does not get any oxygen. Cardiac muscle fibers that is starved of oxygen for more than about five minutes will die. Cardiac muscle does not divide, so dead cardiac muscle cells are not replaced. Coronary heart disease is the leading causes of death of adults in the United States. How a blocked coronary artery can cause a heart attack, and cause part of the heart muscle to die is shown in **Figure** 18.23. Injured cardiac muscle does not contract as well as healthy tissue, so the heart will not work as well as it used to.

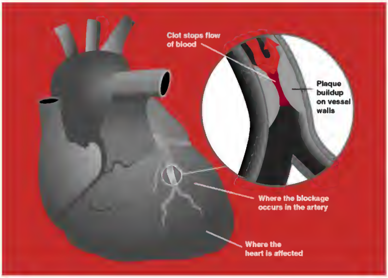

Figure 18.23: A blockage in a coronary artery stops oxygen getting to part of the heart muscle; areas of the heart that depend on the blood flow from the blocked artery are starved of oxygen. (4)

Stroke

Atherosclerosis in the arteries of the brain can lead to a stroke. A **stroke** is a loss of brain function due to a blockage of the blood supply to the brain. It can be caused by a blood clot, a free-floating object that gets caught in a blood vessel, or by a bleeding blood vessel.

Risk factors for stroke include advanced age, high blood pressure, having a previous stroke, diabetes, high cholesterol, and cigarette smoking. Reducing blood pressure is the most important controllable risk factor of stroke. However, many other risk factors, such as avoiding tobacco or quitting tobacco smoking are also important.

Keeping Your Cardiovascular System Healthy

There are many risk factors that can cause a person to develop CVD. A **risk factor** is anything that is linked to an increased chance of developing a disease or an infection. Some of the risk factors for CVD you cannot control, but there are many risk factors you can control.

Risk factors you cannot control include:

- **Age** The older a person is, the greater their chance of developing a cardiovascular disease.
- **Gender** Men under age 64 are much more likely to die of coronary heart disease than women, although the gender difference declines with age.

- **Genetics** Family history of cardiovascular disease increases a person's chance of developing heart disease.

Risk factors you can control include:

- **Tobacco Smoking** Giving up smoking or never starting to smoke is the single most effective way of reducing the risk of heart disease.
- **Diabetes** Having diabetes can cause changes (such as high cholesterol levels) which in themselves are risk factors.
- **High Cholesterol Levels** High amounts of low density lipids in the blood, also called *bad cholesterol,* are a significant risk factor
- **Obesity** Being obese, especially if the fat is deposited mostly in the torso, rather than the hips and thighs, increases risk significantly
- **High Blood Pressure** Hypertension can cause atherosclerosis
- **Lack of Physical Activity** Aerobic activities, such as the one shown in **Figure** 18.24, help keep your heart healthy To reduce the risk of disease, you should be active for at least 60 minutes a day, five days a week (or most days of the week).
- **Poor Eating Habits** Eating mostly foods that are nutrient poor (do not have many nutrients other than fat or carbohydrate) leads to high cholesterol levels and overweight, among other things.

Figure 18.24: Thirty minutes a day of vigorous aerobic activity, such as basketball, is enough to help keep your cardiovascular system healthy. (12)

Although there are uncontrollable risk factors, a person whose family has a history of CVD does not have to develop heart disease. There are many things a person can do to help prevent CVD, even if CVD is in their family. A person who is physically active every day, eats healthfully, and avoids tobacco can lower their chances of developing a CVD.

Men have a higher rate of cardiovascular disease than women do, but it is the number one health problem for women in industrialized countries. The risk for older women (in late adulthood) is almost equal that of older men.

Cardiovascular Disease Awareness: What You Can Do

Being active every day and eating healthfully are two of the most important things you can do to maintain a healthy cardiovascular system. Avoiding tobacco is also very important. You do not to be on a sports team or join a gym to be physically active. For example, shooting hoops at your school or local basketball courts can help keep your heart healthy. *Aerobic activities* are activities that cause your heart to beat faster and allow your muscles to use oxygen to get energy to contract. When done regularly, aerobic activities increase the size of the heart so it pumps blood around the body more efficiently. Aerobic activities also help to keep blood vessels healthy. To stay healthy, teens and children should be active for at least 60 minutes most days of the week.

Limiting the amount of saturated fat in your diet can also keep your heart healthy. Saturated fats are found in dairy foods, meats, cookies, pies, some chocolates, and ice cream. Saturated fats are usually solid at room temperature. Fat gives food flavor and texture. Saturated fats occur naturally in foods that come from animals, such as meat and milk, but they are often added to baked products such as cookies, shown in **Figure** 18.25, to give the foods flavor and texture. Not all fats are harmful to the cardiovascular system. Fats called *monounsaturated* and *polyunsaturated fats* are needed by the body, and should make up most of the fats that you eat in your diet. Monounsaturated and polyunsaturated fats are found in plants and fish, and are usually liquid at room temperature. To learn more about the importance of fats in your diet, read the *Choosing Healthful Foods* lesson of the *Food and the Digestive System* chapter.

Cardiovascular diseases are called *lifestyle diseases* because they are caused mostly by everyday choices that people make, such as what to eat for dinner, or what to do during their free time. For example, watching TV with your dog does not involve much moving around so it does not exercise the body, whereas bringing the dog for a walk outside exercises both of you. Decisions that you make today and everyday - those of developing healthy lifelong habits - will affect your cardiovascular health many years from now.

Many studies have shown that plaque build-up starts in the teen years. However, teens are more concerned about risks such as HIV, accidents, and cancer than cardiovascular disease. One in three people will die from complications due to atherosclerosis. For this reason there is an emphasis on the prevention of CVD through risk reduction. For example, healthy eating, regular physical activity, and avoidance of smoking can greatly decrease a person's chance of developing a CVD.

Figure 18.25: The USDA's MyPyramid recommends that you limit the amount of such foods in your diet to occasional treats; some foods containing saturated fats may contain other nutrients. (2)

Lesson Summary

- Blood pressure is the force exerted by circulating blood on the walls of blood vessels. The force of the contractions put the blood under pressure. Blood pressure is measured by an instrument called a *sphygmomanometer*.
- In the United States the healthy ranges for systolic pressure is less than 120 mm Hg and a diastolic pressure of less than 80 mm Hg. Hypertension is a condition in which a person's blood pressure is always high.
- A cardiovascular disease (CVD) is any disease that affects the cardiovascular system. Atherosclerosis, coronary heart disease, and stroke are examples of CVDs.
- Cardiovascular diseases are lifestyle diseases, they are mostly caused by lifestyle choices that people make. Having a poor diet and not getting enough exercise are two major causes of CVD.

Further Reading / Supplemental Links

- http://mypyramid.gov http://www.presidentschallenge.org/; http://mypyramid.gov
- http://www.cdc.gov/youthcampaign/marketing/tweens/yellowball/index.htm
- http://www.cdc.gov/nccdphp/dnpa/physical/everyone/recommendations/index.htm
- http://www.cdc.gov/bloodpressure http://en.wikipedia.org/wiki/Aerobic_exercise; http://www.cdc.gov/bloodpressure

Review Questions

1. What is the cause of blood pressure?
2. How is the pulse related to blood pressure?
3. Is the blood in veins under pressure? Explain your answer.
4. What is the healthy range for blood pressure?
5. When is a person considered to have hypertension?
6. Why is hypertension called a silent killer?
7. A stroke is often called a *brain attack,* in a similar way to a *heart attack.* How are these two things similar?
8. What is atherosclerosis?
9. What is a risk factor?
10. What is the difference between a controllable risk factor and an uncontrollable risk factor?
11. Why are cardiovascular diseases called lifestyle diseases?
12. Identify three things a person could do to reduce their chances of developing a CVD.

Vocabulary

angina Chest pain caused by the lack of oxygen to the heart muscle; can happen during times of stress or physical activity.

atherosclerosis A chronic inflammation of the walls of arteries that causes swelling and a buildup of material called plaque.

blood pressure The force exerted by circulating blood on the walls of blood vessels.

cardiovascular disease (CVD) Any disease that affects the cardiovascular system, although the term is usually used to describe diseases that are linked to atherosclerosis.

coronary heart disease The end result of the buildup of plaques within the walls of the coronary arteries.

heart attack Event that occurs when the blood supply to a part of the heart is blocked.

hypertension Also called high blood pressure; a condition in which a person's blood pressure is always high; the systolic blood pressure is always 140 mm Hg or higher, and/or their diastolic blood pressure is always 90 mm Hg or higher.

plaque Cell pieces made up of fatty substances, calcium, and connective tissue that build up around the area of inflammation; builds up on the lining of blood vessels.

risk factor Anything that is linked to an increased chance of developing a disease or an infection.

stroke A loss of brain function due to a blockage of the blood supply to the brain.

Points to Consider

- Do you think there is a relationship between the cardiovascular system and the respiratory system? What could it be?
- Do you think hypertension affects the ability of the blood to release carbon dioxide and pick up oxygen in the lungs? Why?

Image Sources

(1) *Capillaries connect arteries and veins.*. Public Domain-gov.

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(3) http://commons.wikimedia.org/wiki/File:Illu_lymph_capillary.png. Public Domain.

(4) http://commons.wikimedia.org/wiki/File:Heart_attack_diagram.png. Public Domain.

(5) http://commons.wikimedia.org/wiki/File:Illu_lymphatic_system.jpg. Public Domain.

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Chapter 19

Respiratory and Excretory Systems

19.1 Lesson 19.1: Respiratory System

Lesson Objectives

- Identify the parts of the respiratory system.
- Identify the main function of the respiratory system.
- Describe how breathing works.
- Outline how the respiratory system and the cardiovascular system work together.
- Identify how breathing and cellular respiration are connected.

Check Your Understanding

- What is an organ system?
- What is the role of the circulatory system?
- How does your blood get oxygen?

Introduction

You breathe mostly without thinking about it. But, do you remember how uncomfortable you felt the last time you had a cold or a cough? You usually do not think about your respiratory system or how it works until there is a problem with it. Every cell in your body depends on your respiratory system. In this lesson, you will learn how your respiratory system works with your cardiovascular system to bring oxygen to every cell in your body.

Roles of the Respiratory System

Your respiratory system is made up of the tissues and organs that allow oxygen to enter and carbon dioxide to leave your body. These structures include your nose, mouth, larynx, pharynx, lungs, and diaphragm. These structures are shown in **Figure** 19.1. The main function of the respiratory system is to bring oxygen into the body and releases carbon dioxide into the atmosphere.

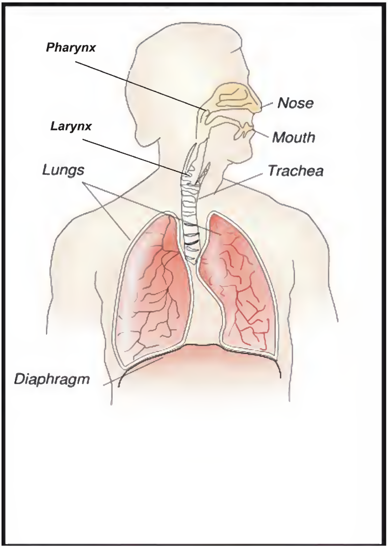

Figure 19.1: The respiratory system; air moves in through the nose and mouth, and down the trachea which is a long straight tube in the chest. (14)

Parts of the Respiratory System

Figure 1 shows many of the structures of the respiratory system. Each of the parts has a specific job. The parts of the respiratory system include:

The **diaphragm** is a sheet of muscle that extends across the bottom of the rib cage. It performs an important function in respiration. When the diaphragm contracts the chest volume gets larger and the lungs take in air. When the diaphragm relaxes, the chest volume gets smaller and air is pushed out of the lungs.

The **nose and nasal cavity** filters, warms, and moistens the inhaled air. The nose hairs and mucus produced by the cells that line the nose catch airborne particles and prevent them from reaching the lungs.

Behind the nasal cavity, air next passes through the **pharynx,** a long tube that is shared with the digestive system. Both food and air pass through the pharynx. A flap of connective tissue called the *epiglottis* closes over the trachea when food is swallowed to prevent choking or inhaling food.

The **larynx,** also called the *voicebox,* is found just below the point at which the pharynx splits into the trachea and the esophagus. Your voice comes from your larynx. Air from the lungs passes across thin membranes in the larynx and produces sound.

The **trachea,** or wind pipe, is a long tube that leads down to the chest where it divides into the right and left **bronchi** in the lungs. The bronchi branch out into smaller bronchioles in each lung.

The bronchioles lead to the alveoli. **Alveoli** are the little sacs at the end of the bronchioles. They look like little bunches of grapes at the end of the bronchioles, as shown in **Figure** 19.2. Most of the gas exchange occurs in the alveoli. **Gas exchange** is the movement of oxygen across a membrane and into the blood and the movement of carbon dioxide out of the blood.

How We Breathe

Most of the time, you breathe without thinking of it. Breathing is mostly an involuntary action that is controlled by a part of your brain that also controls your heart beat. If you swim, do yoga, or sing, you know you can also control your breathing.

Taking air into the body through the nose and mouth is called **inhalation.** Pushing air out of the body through the nose or mouth is called **exhalation.** The man in **Figure** 19.3 is exhaling before he surfaces in the pool water. The lungs cannot move by themselves. As mentioned above, air moves into and out of the lungs by the movement of muscles. The diaphragm and rib muscles contract and relax to move air in to and out of the lungs.

During inhalation, the diaphragm contracts and moves downward. The rib muscles contract

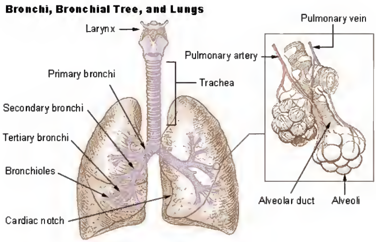

Figure 19.2: The alveoli are the tiny grape-like structures in the lungs and the sites of gas exchange. (11)

Figure 19.3: Being able to control breathing is important for many activities, such as swimming. The man in the photograph is exhaling before he surfaces the water. (10)

and cause the ribs to move outward. This causes the chest volume to increase. Because the chest volume is larger, the air pressure inside the lungs is less than the air pressure outside. This difference in air pressures causes air to be sucked into the lungs. When the diaphragm and rib muscles relax, air is pushed out of the lungs. Exhalation is normally a passive process, similar to letting the air out of a balloon.

The walls of the alveoli are very thin and are permeable to gases. The alveoli are lined with capillaries, the walls of which are also thin enough to allow gas exchange. These capillaries are shown in **Figure** 19.4. Oxygen diffuses from the alveoli to the blood in the capillaries that surround the alveoli. At the same time, carbon dioxide diffuses in the opposite direction, from capillary blood to the alveoli. At this point, the pulmonary blood is oxygen-rich, and the lungs are holding carbon dioxide. Exhalation follows, thereby ridding the body of the carbon dioxide and completing the cycle of respiration.

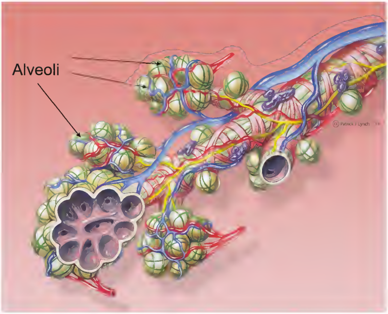

Figure 19.4: The bronchi and alveoli; during respiration, oxygen gets pulled into the lungs and enters the blood by passing across the thin alveoli membranes and into the capillaries. (12)

Breathing and Respiration

When you breath in, oxygen is drawn in through the mouth and down into the lungs. The oxygen then passes across the thin lining of the capillaries and into the blood. The oxygen molecules are carried to the body cells by the blood. Carbon dioxide from the body cells is carried by the blood to the lungs where it is released into the air. The process of getting oxygen into the body and releasing carbon dioxide is called **respiration.**

Sometimes breathing is called *respiration*. But, there is much more to respiration than just breathing. There are actually two parts to respiration. The movement of oxygen into the body and carbon dioxide out of the body is called *external respiration*. The exchange of gases between the blood and the cells of the body is celled *internal respiration*.

The Journey of a Breath of Air

Breathing is only part of the process of delivering oxygen to where it is needed in the body. **Gas exchange** occurs in the alveoli by passive diffusion of gases between the alveoli and the blood in the capillaries of the lungs. The passive diffusion of oxygen and carbon dioxide is shown in **Figure** 19.5.

Recall that diffusion is the movement of substances from an area of higher concentration to an area of lower concentration. The difference between the high concentration of oxygen (O_2) in the alveoli and the low O_2 concentration of the blood in the capillaries is enough to cause O_2 molecules to diffuse across the thin walls of the alveoli and capillaries and into the blood. Carbon dioxide (CO_2) moves out of the blood and into the alveoli in a similar way.

After leaving the lungs, the oxygenated blood returns to the heart to be pumped through the aorta and around the body. The oxygenated blood travels through the aorta, to the smaller arteries and finally to the capillaries where gas exchange occurs. The oxygen molecules move out of the capillaries and into the body cells. While oxygen diffuses from the capillaries and into body cells, carbon dioxide diffuses from the cells into the capillaries.

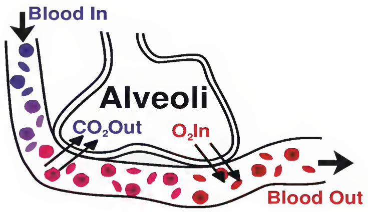

Figure 19.5: Gas exchange is the movement of oxygen into the blood and carbon dioxide out of the blood. (17)

Breathing and Cellular Respiration

The oxygen that arrives at the cells from the lungs is used by the cells to release the energy stored in molecules of sugar. **Cellular respiration** is the process of breaking down glucose to release energy (see the *Cell Functions* chapter). The waste products of cellular respiration include carbon dioxide and water. The carbon dioxide molecules move out of the cells and into the capillaries that surround the cells. The carbon dioxide is removed from the body by the lungs.

Lesson Summary

- Your respiratory system is made up of the tissues and organs that allow oxygen to enter and carbon dioxide to leave your body. These structures include your nose, mouth, larynx, pharynx, lungs, and diaphragm. The main function of the respiratory system is to bring oxygen into the body and releases carbon dioxide into the atmosphere. During inhalation, the diaphragm contracts and moved downward. The rib muscles contract and cause the ribs to move outward, causing the chest volume to increase. Air pressure inside the lungs is less than the air pressure outside so air is sucked into the lungs. When the diaphragm and rib muscles relax, air is pushed out of the lungs. Exhalation is normally a passive process.
- Oxygen enters the lungs, passes through the alveoli and into the blood. The oxygen is carried around the body in blood vessels. In a similar way, carbon dioxide, a waste product, moves into the blood capillaries by passive diffusion and is brought to the lungs in the pulmonary circulation. The carbon dioxide is released into the air during exhalation. The oxygen that arrives from the lungs is used by the cells during cellular respiration to release the energy stored in molecules of sugar. A waste product of cellular respiration, carbon dioxide, is removed from the body by exhalation.

Review Questions

1. Name the parts of the respiratory system.
2. What is the main function of the respiratory system?
3. A classmate says that the lung muscles cause the lungs to move during breathing. Do you agree with your classmate?
4. How do the respiratory system and the cardiovascular system work together?
5. Breathing is an involuntary action. Does this mean that you cannot control your breathing?
6. In what part of the lung does gas exchange occur?
7. What is the difference between breathing and respiration?
8. Identify how breathing and cellular respiration are connected.
9. What is the important gas that is carried into the lungs during inhalation?

10. What is the name of the waste gas that is released during exhalation?
11. If a disease caused the alveoli to collapse, how might this affect a person's health?

Further Reading / Supplemental Links

- http://en.wikipedia.org/wiki

Vocabulary

alveoli Little "sacs" at the end of the bronchioles where most of the gas exchange occurs.

diaphragm A sheet of muscle that extends across the bottom of the rib cage. When the diaphragm contracts the chest volume gets larger and the lungs take in air; when the diaphragm relaxes, the chest volume gets smaller and air is pushed out of the lungs.

epiglottis A flap of connective tissue that closes over the trachea when food is swallowed to prevent choking or inhaling food.

exhalation Pushing air out of the body through the nose or mouth.

external respiration The movement of oxygen into the body and carbon dioxide out of the body.

gas exchange The movement of oxygen across a membrane and into the blood and the movement of carbon dioxide out of the blood.

inhalation Taking air into the body through the nose and mouth.

internal respiration The exchange of gases between the blood and the cells of the body.

larynx Found just below the point at which the pharynx splits into the trachea and the esophagus. Your voice comes from your larynx; air from the lungs passes across thin membranes in the larynx and produces sound; also called the voicebox.

pharynx A long tube that is shared with the digestive system; both food and air pass through the pharynx.

respiration The process of getting oxygen into the body and releasing carbon dioxide.

trachea A long tube that leads down to the chest where it divides into the right and left bronchi in the lungs; also called the windpipe.

Points to Consider

- How do you think the health of your respiratory system might affect the health of other body systems?

19.2 Lesson 19.2: Health of the Respiratory System

Lesson Objectives

- Identify the organs affected by a respiratory disease.
- Identify how a respiratory disease can affect the rest of the body.
- Describe how asthma affects breathing.
- Outline how smoking affects the respiratory system.
- Identify what you can do to keep your respiratory system healthy.

Check Your Understanding

- What is the role of the respiratory system?
- What are some of the organs of the respiratory system?

Introduction

Most of the time your respiratory system works well, and you don't notice it doing its job. But your respiratory system can sometimes be knocked out of homeostasis. Recall that homeostasis is the balancing act your body performs that keeps conditions in your body stable. Anything that disrupts the respiratory system from doing its job disrupts homeostasis. When homeostasis no longer exists, there is disease. There are many causes of respiratory diseases, and many ways to treat such diseases. In this lesson you will learn about some of the most common respiratory diseases, and what you can do to help avoid them. You will also learn how the use of tobacco disrupts homeostasis, which leads to some of the most serious respiratory diseases.

Respiratory System Disease

In general, diseases that last a short time are called *acute diseases*. Other diseases can last for a long time, perhaps years. Diseases that last for a long time are called *chronic diseases*. Both acute and chronic diseases affect the respiratory system. **Respiratory diseases** are diseases of the lungs, bronchial tubes, trachea, nose, and throat (**Figure** 19.6). These diseases can range from a mild cold to a severe case of bacterial pneumonia. Respiratory

diseases are common and may cause illness or death. Some respiratory diseases are caused by bacteria while others are caused by viruses, environmental pollutants such as tobacco smoke, or are hereditary.

Figure 19.6: This boy is suffering from whooping cough (also known as *pertussis*) which gets its name from the loud whooping sound that is made when the person inhales during a coughing fit. (4)

Bronchitis

Bronchitis is an inflammation of the bronchi. *Acute bronchitis* is usually caused by viruses or bacteria and may last several days or weeks. It is characterized by a cough that produces phlegm (mucus). Symptoms include shortness of breath and wheezing, which are related to the inflammation of the airways. Acute bronchitis is usually treated with antibiotics.

Chronic bronchitis may not be caused by a bacterium or a virus. Chronic bronchitis is defined as having a cough that produces phlegm, for at least three months in a two-year period. Tobacco smoking is the most common cause of chronic bronchitis, but it can be caused by environmental pollution such as smog and dust. It is generally part of a syndrome called *chronic obstructive pulmonary disease* (COPD), which we will learn about later. Treatments for bronchitis include antibiotics and steroid drugs to reduce inflammation.

Asthma

Asthma is a chronic illness in which the bronchioles are inflamed and become narrow, as shown in **Figure** 19.7. The muscles around the bronchioles contract which narrows the airways further. Large amounts of mucus are also made by the cells that line the lungs. A person with asthma has difficulty breathing. Their chest feels tight and they wheeze.

Asthma can be caused by different things such as exposure to an allergen. An **allergen** is any antigen that is not an infectious organism. Allergens can cause allergic reactions. Common allergens that cause asthma are mold, dust, or pet hair. Asthma can also be caused by cold air, warm air, moist air, exercise, or stress. The most common asthma triggers are viral illnesses such as the common cold. The symptoms of asthma can usually be controlled with medicine. *Bronchodilators* are drugs that reduce inflammation of the bronchioles allowing air through.

Asthma is not contagious and cannot be passed onto other people. Sometimes people with asthma are afraid that being active could cause them to have an asthma attack. Having asthma does not mean that you have to miss out on being active. Many teens that have asthma are active every day. Asthma cannot be cured, but is treatable with medicines. Children and adolescents who have asthma can still lead active lives if they control their asthma. Asthma can be controlled by taking medication and by avoiding contact with environmental triggers for asthma.

Pneumonia

Pneumonia is an illness in which the alveoli become inflamed and flooded with fluid. Pneumonia is a restrictive respiratory disease. Gas exchange cannot happen properly across the alveoli membranes. Pneumonia can be caused by many things. Infection by bacteria, viruses, fungi, or parasites can cause pneumonia. An injury caused by chemicals or a physical injury

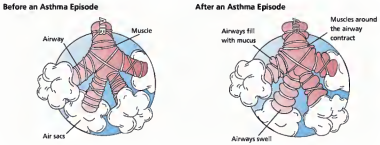

Figure 19.7: The two reactions that lead to asthma are when the bronchioles swell and the muscles around the bronchioles contract. (6)

to the lungs can also cause pneumonia. Symptoms of pneumonia include cough, chest pain, fever, and difficulty in breathing. Treatment depends on the cause of pneumonia. Bacterial pneumonia is treated with antibiotics.

Pneumonia is a common illness which occurs in all age groups, and is a leading cause of death among the elderly and people who are chronically and terminally ill. Vaccines to prevent certain types of pneumonia are available.

Tuberculosis

Tuberculosis (TB) is a common and often deadly infectious disease caused by a type of bacterium called *mycobacterium.* Tuberculosis most commonly attacks the lungs but can also affect other parts of the body. Mycobacteria in the alveoli cause an immune reaction in the body that damages the alveoli. TB is a chronic disease, but most people who become infected do not develop the full disease. The TB mycobacteria are spread in the air when people who have the disease cough, sneeze or spit. To help prevent the spread of the disease, public health notices, such as the one in **Figure** 19.8, reminded people how to stop the spread of the disease. Currently, drug resistant forms of TB are creating a new challenge for health professionals.

Cancer

Lung cancer is a disease where the cells that line the lungs grow out of control. The growing mass of cells pushes into nearby tissues and can affect how these tissues work. Lung cancer, which is the most common cause of cancer-related death in men and the second most common in women, is responsible for 1.3 million deaths worldwide every year The most common symptoms are shortness of breath, coughing (including coughing up blood), and weight loss. The most common cause of lung cancer is exposure to tobacco smoke.

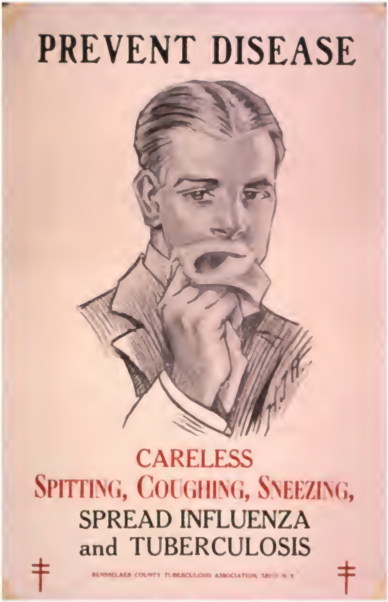

Figure 19.8: A public health notice from the early 20th century reminded people that TB could be spread very easily. (9)

Emphysema

Emphysema is a chronic lung disease caused by loss of elasticity of the lung tissue. The surfaces of healthy alveoli are springy and elastic. They stretch out a little when full of air and relax when air leaves them. But the breakdown of the tissues that support the alveoli and the capillaries that feed the alveoli cause the alveoli to become hard and stiff. Eventually the walls of the alveoli break down and the alveoli become larger. When alveoli become larger, the amount of oxygen that can enter the blood with each breath is reduced. Much of the oxygen that gets into the large alveoli cannot be absorbed across the alveoli walls into the blood. Symptoms of emphysema include shortness of breath on exertion (usually when climbing stairs or a hill). Damage to the alveoli, which can be seen in **Figure** 19.9, is not curable. Smoking is a leading cause of emphysema.

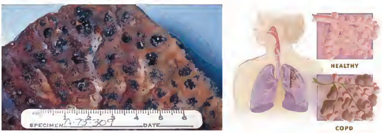

Figure 19.9: The lung of a smoker who had emphysema (left); the black areas are enlarged alveoli and tar, a sticky, black substance found in tobacco smoke is evident, and (right) COPD (Chronic obstructive pulmonary disease), a tobacco-related disease that is characterized by emphysema. (18)

Causes of Respiratory Diseases

Pathogens

Many respiratory diseases are caused by pathogens. A **pathogen** is an organism that causes disease in another organism. Certain bacteria, viruses, and fungi are pathogens of the respiratory system. The common cold and flu are caused by viruses. The influenza virus that causes the flu is shown in **Figure** 19.10. Tuberculosis, whooping cough, and acute bronchitis are caused by bacteria. The pathogens that cause colds, flu, and TB can be passed from person to person by coughing, sneezing, and by spitting.

Pollution

Air quality is related to several respiratory diseases. Asthma, heart and lung diseases, allergies, and several types of cancers are all linked to air quality. Air pollution can be caused by outdoor pollution or indoor pollution. Outdoor air pollution can be caused by car exhaust fumes, smoke from factories and forest fires, volcanoes, and animal feces. Some of

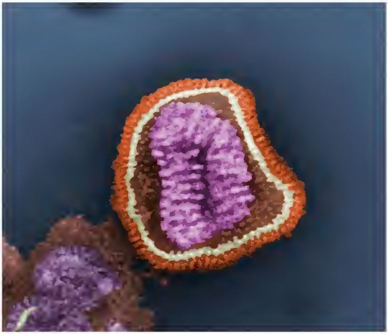

Figure 19.10: This is the influenza virus that causes the flu; the CDC (The Center for Disease Control and Prevention) recommends that children between the ages of 6 months and 19 years get a flu vaccination each year. (16)

the pollutants of concern include particulates, carbon dioxide, sulfur oxides, and lead. These pollutants contain tiny particles that can get "stuck" in the lining of the respiratory system and irritate the lungs. Indoor air pollution can be caused by tobacco smoke, dust, mold, insects, rodents, and cleaning chemicals.

Lifestyle Choices

Smoking is the major cause of chronic respiratory disease as well as cardiovascular disease and cancer. Exposure to tobacco smoke, by smoking or by breathing air that contains tobacco smoke is the leading cause of preventable death in the U.S. Regular smokers die about 10 years earlier than nonsmokers do. The Centers for Disease Control and Prevention (CDC) describes tobacco use as "the single most important preventable risk to human health in developed countries and an important cause of premature death worldwide.

Dangers of Smoking

Tobacco use, particularly cigarette smoking, is the single most preventable cause of death in the United States. Cigarette smoking alone is directly responsible for approximately 30 percent of all cancer deaths annually in the United States. The main health risks of using tobacco are linked to diseases of the cardiovascular system and respiratory system.

Cardiovascular diseases caused by smoking include heart disease and stroke. Diseases of the respiratory system that are caused by exposure to tobacco smoke include emphysema, lung cancer, and cancers of the larynx and mouth. Cigarette smoking causes 87 percent of lung cancer deaths. Smoking and using tobacco is also linked to the risk of developing other types of cancer such as pancreatic and stomach cancer.

Cigarettes, like the ones shown in **Figure** 19.11, are a major source of indoor air pollution. Cigarette smoke contains about 4,000 substances, including over 60 cancer-causing chemicals. Many of these substances, such as carbon monoxide, tar, arsenic, and lead, are toxic to the body. Non-smokers can also be affected by tobacco smoke. Exposure to secondhand smoke, also known as **environmental tobacco smoke (ETS)**, greatly increases the risk of lung cancer and heart disease in nonsmokers.

Chronic obstructive pulmonary disease (COPD) is a disease of the lungs in which the airways become narrowed. This leads to a limitation of the flow of air to and from the lungs causing shortness of breath. The limitation of airflow usually gets worse over time. COPD is most commonly caused by smoking. Gases and particles in tobacco smoke trigger an abnormal inflammatory response in the lung. The inflammatory response in the larger airways is known as chronic bronchitis. In the alveoli, the inflammatory response causes the breakdown of the tissues in the lungs, leading to emphysema.

Figure 19.11: Tobacco use, particularly cigarette smoking, is the single most preventable cause of death in the United States. (7)

Keeping Your Respiratory System Healthy

Many of the diseases related to smoking are called **lifestyle diseases,** diseases that are caused by choices that people make in their daily lives. For example, the choice to smoke can lead to cancer in later life. But, there are many things you can do to help keep your respiratory system healthy. Some of these are listed here:

Avoid Smoking

Never smoking or quitting now are the most effective ways to reduce your risk of developing chronic respiratory diseases such as cancer.

Eat Well, Exercise Regularly, and Get Rest

Eating a healthful diet, getting enough sleep, and being active every day can help keep your immune system strong.

Wash Your Hands

Washing your hands often, and after sneezing, coughing or blowing your nose help to protect you and others from diseases. Washing your hands for 20 seconds with soap and warm water can help prevent colds and flu. Some viruses and bacteria can live from 20 minutes up to 2 hours or more on surfaces like cafeteria tables, doorknobs, and desks. A public health notice that shows people how to prevent the spread of respiratory diseases is shown in **Figure** 19.12.

Avoid Contact with Others When Sick

Do not go to school or to other public places when you are sick. You risk spreading your illness to other people and getting sicker if you catch something else.

Visit Your Doctor

Getting the recommended vaccinations can help prevent diseases such as whooping cough and flu. Seeking medical help for diseases such as asthma can help control the severity of the disease.

Figure 19.12: *Cover your Cough; Clean your Hands* is a public health campaign that reminds people of the quickest and easiest ways to avoid spreading respiratory diseases such as colds and the flu. (5)

Lesson Summary

- Respiratory diseases are diseases that affect the lungs, bronchial tubes, trachea, nose, and throat. Respiratory diseases can reduce the amount of oxygen that gets into the blood. Asthma is an illness in which the bronchioles are inflamed and become narrow. The muscles around the bronchioles contract which narrows the airways further.
- Difficulty in breathing happens because of the inflammation, contraction of the muscles, and the production of mucus by the cells that line the bronchioles. Diseases of the respiratory system that are caused by exposure to tobacco smoke include emphysema, lung cancer and cancers of the larynx and mouth.
- Cigarette smoking causes 87 percent of lung cancer deaths. Smoking and using tobacco is also linked to the risk of developing other types of cancer. Avoiding smoking, getting enough exercise, and washing your hands often are three things you can do to help protect your respiratory system from illness.

Further Reading / Supplemental Links

- http://www.cdc.gov/vaccines/vpd-vac/pertussis/default.htm
- http://www.cdc.gov/tobacco/data_statistics/fact_sheets/youth_data/youth_tobacco.htm
- http://www.cdc.gov/asthma/children.htm http://www.cdc.gov/nceh/globalhealth/projects/airpollution.htm; http://www.cdc.gov/asthma/children.htm
- http://www.bmj.com/cgi/content/abstract/328/7455/1519 http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5644a2.htm; http://www.bmj.com/cgi/content/abstract/328/7455/1519
- http://www.cdc.gov/flu/protect/keyfacts.htm http://www.cdc.gov/germstopper/home_work_school.htm; http://www.cdc.gov/flu/protect/keyfacts.htm
- http://www.cancer.gov/cancertopics/factsheet/Tobacco/cancer http://en.wikipedia.org/wiki/Cigarette_smoking; http://www.cancer.gov/cancertopics/factsheet/Tobacco/cancer
- http://www.cancer.gov/cancertopics/factsheet/Tobacco/cancer
- http://www.cdc.gov/tobacco/data_statistics/sgr/sgr_2004/sgranimation/html/welcome.html
- http://www.cdc.gov/flu/protect/covercough.htm

Review Questions

1. Identify the organs that are affected by a respiratory disease.
2. How might a respiratory disease affect the rest of the body?
3. How does asthma affects the bronchioles?
4. Medicines called bronchodilators are used to treat the symptoms of asthma. What

action do you think these drugs have on the lungs?
5. What lifestyle activity has the largest health impact on the respiratory system?
6. Identify three diseases are linked to tobacco smoking.
7. Identify three things that can cause a respiratory disease.
8. What are two things you can do to keep your respiratory system healthy?
9. Pneumonia is a disease in which the alveoli fill up with fluid. How might this affect the lungs' ability to absorb oxygen?
10. How can washing your hands help prevent you from catching a cold?

Vocabulary

acute disease A disease that lasts a short time.

allergen Any antigen that is not an infectious organism, such as mold, dust, or pet hair.

asthma A chronic illness in which the bronchioles are inflamed and become narrow.

bronchodilators Drugs that reduce inflammation of the bronchioles allowing air through.

bronchitis An inflammation of the bronchi.

chronic bronchitis Having a cough that produces phlegm, for at least three months in a two-year period.

chronic disease A disease that lasts for a long time, perhaps a few years or longer.

chronic obstructive pulmonary disease (COPD) A disease of the lungs in which the airways become narrowed; leads to a limitation of the flow of air to and from the lungs causing shortness of breath.

emphysema A chronic lung disease caused by loss of elasticity of the lung tissue.

environmental tobacco smoke (ETS) Secondhand smoke, which greatly increases the risk of lung cancer and heart disease in nonsmokers.

lifestyle disease A disease that is caused by choices that people make in their daily lives.

lung cancer A disease where the cells that line the lungs grow out of control; the growing mass of cells pushes into nearby tissues and can affect how these tissues work.

pathogen An organism that causes disease in another organism; certain bacteria, viruses, and fungi are pathogens of the respiratory system.

pertussis Whooping cough; gets its name from the loud whooping sound that is made when the person inhales during a coughing fit.

pneumonia An illness in which the alveoli become inflamed and flooded with fluid.

respiratory disease A disease of the lungs, bronchial tubes, trachea, nose, and/or throat.

tuberculosis (TB) A common and often deadly infectious disease caused by a type of bacterium called *mycobacterium*.

Points to Consider

- The respiratory system gets rids of a certain type of wastes. What type of wastes do you think are removed by your respiratory system?

19.3 Lesson 19.3: Excretory System

Lesson Objectives

- Identify the functions of the excretory system.
- List the organs of the excretory system.
- Describe the parts of urinary system.
- Outline how the kidneys filter blood.
- Identify three disorders of the urinary system.

Check Your Understanding

- What are some "wastes" that must be removed from your body?
- Do your circulatory and respiratory systems remove "waste?"

Introduction

One of the most important homeostatic jobs your body does it to keep the right amount of water and salts inside your body. Too much water and your cells would swell and burst. Too little water and your cells would shrivel up like an old apple. Either extreme would cause

illness and death of cells, tissues, and organs. The organs of your excretory system help to keep the correct balance of water and salts within your body.

Your body also needs to remove the wastes that build up from the metabolic activity of cells and digestion. These wastes include carbon dioxide, urea, and certain plant materials. If these wastes were not removed, your cells would stop working and you would get very sick. In this lesson you will learn how waste is removed from the body, and how the kidneys filter waste from the blood.

The Excretory System

The **excretory system** is the organ system that maintains homeostasis by keeping the correct balance of water and salts in your body. It also helps to release wastes from the body. **Excretion** is the process of removing wastes from the body. The organs of the excretory system are also parts of other organ systems. For example, your lungs are part of the respiratory system. Your lungs remove carbon dioxide from your body so they are also part of the excretory system. More organs of the excretory system, and the other organs systems of which they are part are listed in **Table** (19.1).

Table 1: Organs of the Excretory System

Table 19.1: **Organs of the Excretory System**

Organ(s)	Function	Other Organ System of which it is Part
Lungs	Remove carbon dioxide	Respiratory system
Skin	Sweat glands remove water, salts, and other wastes	Integumentary system
Large intestine	Removes solid waste and some water in the form of feces	Digestive system
Kidneys	Remove urea, salts, and excess water from the blood	Urinary system

Functions of the Excretory System

The excretory system controls the chemical make-up of body fluids. The organs of the excretory system remove metabolic wastes. They also maintain the proper concentrations of water, salts, and nutrients in the body. In this way the excretory system has an important homeostatic job.

Your body takes nutrients from food and uses them for energy, growth, and repair. After

your body has taken what it needs from the food, waste products are left behind in the blood and in the large intestine. These waste products need to be removed from the body. The kidneys work with the lungs, skin, and intestines to keep the correct balance of nutrients, salts and water in your body.

The Urinary System

Sometimes and confusingly, the urinary system is called the excretory system. But, the urinary system is only a part of the excretory system. Recall that the excretory system is made up of the skin, lungs, and large intestine as well as the kidneys. The **urinary system** is the organ system that makes, stores, and gets rid of urine. It includes two kidneys, two ureters, the bladder, and the urethra. The urinary system is shown in **Figure** 19.13.

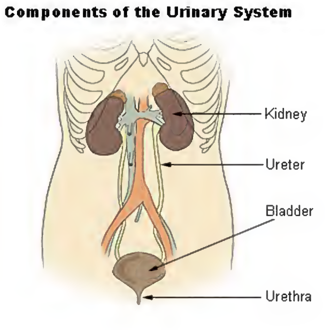

Figure 19.13: The kidneys filter the blood that passes through them and the urinary bladder stores the urine until it is released from the body. (8)

Organs of the Urinary System

As you can see from Figure 1, the kidneys are two bean-shaped organs. The **kidneys** filter and clean the blood and form urine. They are about the size of your fists and are found near the middle of the back, just below your rib cage. The **ureters** are tube-shaped structures that bring urine from the kidneys to the urinary bladder. The **urinary bladder** is a hollow,

muscular, and elastic-walled organ. It is shaped a little like a balloon. It is the organ that collects urine which comes from the kidneys. Urine leaves the body through the **urethra.**

What is Urine?

Urine is a liquid that is formed by the kidneys when they filter wastes from the blood. Urine contains mostly water and also dissolved salts and nitrogen-containing molecules. The amount of urine excreted from the body depends on many things. Some of these include the amounts of fluid and food a person consumes and how much fluid they have lost in sweat and breathing.

Urine is can range from colorless to dark yellow, but is usually a pale yellow color. Dilute urine is light yellow in color. Concentrated urine is dark yellow or may be brown. The darker the urine, the less water it contains.

The urinary system removes a type of waste called *urea* from your blood. **Urea** is a nitrogen-containing molecule that is made when foods containing protein, such as meat, poultry, and certain vegetables, are broken down in the body. Urea and other wastes are carried in the bloodstream to the kidneys were they are removed and form urine.

How the Kidneys Filter Wastes

The kidneys are important organs in maintaining homeostasis. Kidneys perform a number of homeostatic functions:

- Maintain the volume of body fluids
- Maintain the balance of salt ions in body fluids
- Excrete harmful nitrogenous wastes (metabolic by-products) such as urea, ammonia, and uric acid

There are many blood vessels in the kidneys, as you can see in **Figure** 19.14. The kidneys remove urea from the blood through tiny filtering units called *nephrons*. **Nephrons** are tiny, tube-shaped structures found inside each kidney. A nephron is shown in **Figure** 19.15. Each kidney has up to a million nephrons. Each nephron collects a small amount of fluid and waste products from a small group of capillaries. If the body is in need of more water, water is removed from the fluid inside the nephron and is returned to the blood. The fluid within nephrons is carried out into a larger tube in the kidney called a *ureter* which you can see in **Figure** 19.14. Urea, together with water and other wastes, forms the urine as it passes through the nephrons and the kidney.

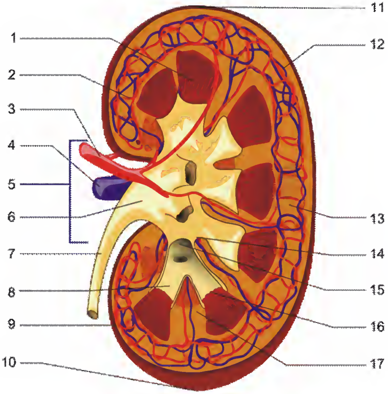

Figure 19.14: Structures of the kidney; fluid leaks from the capillaries and into the nephrons where the fluid forms urine then moves to the ureter and on to the bladder. (1)

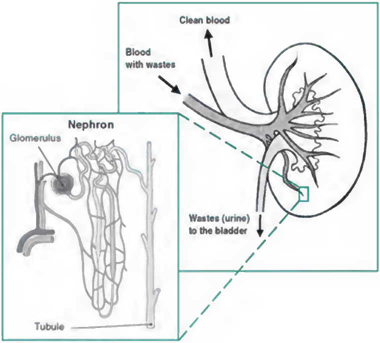

Figure 19.15: The location of nephrons in the kidney; the glomerulus is the network of blood vessels that filter liquid into the nephron, collects in the nephron tubules, and moves to the bladder through the ureter. (13)

Formation of Urine

The process of urine formation is as follows:

1. Blood flows into the kidney through the renal artery, shown in Figure 2. The renal artery branches into capillaries inside the kidney. Capillaries and the nephrons lie very close to each other in the kidney.
2. The blood pressure within the capillaries causes water and solutes such as salts, sugars, and urea to leave the capillaries and move into the nephron.
3. The water and solutes move along through the tube-shaped nephron to a lower part of the nephron. At this point most of the water and solutes are returned to the capillaries that surround the nephron.
4. The fluid that remains in the nephron at this point is called urine.
5. The blood that leaves the kidney in the renal vein has much less waste than the blood that entered the kidney.
6. The urine is collected in the ureters and is moved to the urinary bladder where it is stored.

Nephrons filter 125 ml (about ¼ cup) of body fluid per minute. In a 24-hour period nephrons produce about 180 liters of filtrate, of which 178.5 liters are reabsorbed. The remaining 1.5 liters of fluid forms urine.

Urine enters the bladder through the ureters. Similar to a balloon, the walls of the bladder are stretchy. The stretchy walls allow the bladder to hold a large amount of urine. The bladder can hold about 400 to 620 mL (about 1½ to 2½ cups) of urine, but may also hold more if the urine cannot be released immediately. **Urination** is the process of releasing urine from the body. Urine leaves the body through the urethra.

Nerves in the bladder tell you when it is time to urinate. As the bladder first fills with urine, you may notice a feeling that you need to urinate. The urge to urinate becomes stronger as the bladder continues to fill up.

Brain Control

The kidneys never stop filtering waste products from the blood, so they are always producing urine. The amount of urine your kidneys produce is dependent on the amount of fluid in your body. Your body loses water through sweating, breathing, and urination. The water and other fluids you drink every day help to replace the lost water. This water ends up circulating in the blood because blood plasma is mostly water.

The kidneys will normally adjust to the level of water a person drinks. For example, if a person suddenly increases their water intake, the kidneys will produce more diluted (watery) urine. If a person drinks much less fluid than they usually do, their urine will be more concentrated (contain much less water).

The filtering action of the kidneys is controlled by the pituitary gland. The pituitary gland is about the size of a pea and is found below the brain, as shown in **Figure** 19.16. The pituitary gland is also part of the endocrine system. The pituitary gland releases hormones which affect the ability of the kidneys to filter water from the blood.

The absorption of water back into blood is controlled by a hormone called *antidiuretic hormone (ADH)*. ADH is released from the pituitary gland in the brain. One of the most important roles of ADH is to control the body's ability to hold onto water. If a person does not drink enough water, ADH is released and it causes the kidneys to remove more water from the urine. The urine is more concentrated and is less in volume.

When too much fluid is present in the blood, the amount of ADH in the blood is reduced. This increases the amount of water that filters into the nephrons. The kidneys then produce a large volume of more dilute urine.

Figure 19.16: The pituitary gland is found directly below the brain and releases hormones that control the production of urine. (2)

Excretory System Problems

The urinary system controls the amount of water in the body, and removes wastes, so any problem with the urinary system can badly affect many other body systems. Some common urinary system problems are described here.

Kidney Stones

In some cases, certain mineral wastes in urine crystallize and form kidney stones like the one shown in**Figure** 19.17. Stones form in the kidneys and may be found anywhere in the

urinary system. They vary in size. Some stones cause great pain while others cause very little pain. Some stones may need to be removed by surgery or ultrasound treatments.

Figure 19.17: A kidney stone; the stones can form anywhere in the urinary system. (15)

Kidney failure

Kidney failure results when the kidneys are not able to regulate water and chemicals in the body or remove waste products from the blood. If the kidneys are unable to filter wastes from the blood, the wastes build up in the body. Homeostasis is disrupted because the ions and fluids in the body are out of balance.

Kidney failure can be caused by an accident that injures the kidneys, the loss of a lot of blood, or it can be caused by some drugs or poisons. Kidney failure may lead to permanent loss of kidney function. But if the kidneys are not seriously damaged, they may recover. Chronic kidney disease is the gradual reduction of kidney function that may lead to permanent kidney failure.

A person who has lost kidney function may need to undergo kidney dialysis. Kidney dialysis is the process of artificially filtering the blood of wastes. A dialysis machine (also called a

hemodialyzer) filters the blood of waste by pumping it through a semipermeable membrane. The cleansed blood is then returned to the patient's body. A dialysis machine is shown in **Figure** 19.18.

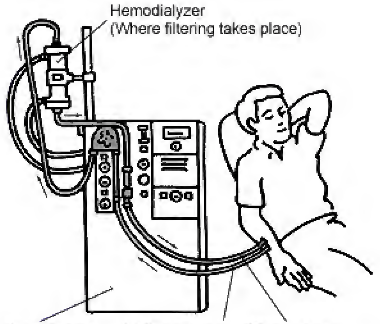

Figure 19.18: During hemodialysis, a patient's blood is sent through a filter that removes waste products and the clean blood is returned to the body. (3)

Urinary tract infections (UTIs)

Urinary tract infections are bacterial infections of any part of the urinary tract. When bacteria get into the bladder or kidney and multiply in the urine, they cause a UTI. The most common type of UTI is a bladder infection. Women get UTIs more often than men. UTIs are often treated with antibiotics.

Lesson Summary

- The excretory system controls the chemical make-up of body fluids. The organs of the excretory system remove metabolic wastes. They also maintain the proper concentrations of water, salts, and nutrients in the body.

- The lungs, skin, kidneys, and large intestine are all part of the excretory system. The urinary system is made up of the kidneys, the ureters, the bladder, and the urethra. The filtering structures of the kidneys are the nephrons.
- Water and waste molecules move out of the blood capillaries and into the nephrons. Most of the water returns to the blood. Urine collects in the nephron and moves to the urinary bladder through the ureters.
- The filtering action of the kidneys is controlled by the pituitary gland. ADH is the hormone that controls the uptake of water from the kidneys. Disorders of the urinary system include kidney stones, kidney disease and urinary tract infections.

Review Questions

1. What are the functions of the excretory system?
2. List the organs that make up the excretory system.
3. What is the difference between the urinary system and the excretory system?
4. What is urine made up of?
5. Outline how the kidneys filter blood.
6. What is the purpose of the urinary bladder?
7. The walls of the urinary bladder are stretchy, what do you think is the advantage to having these stretchy walls?
8. What connects the kidneys to the urinary bladder?
9. What does antidiuretic hormone do?
10. What is a urinary tract infection?
11. Why is kidney failure such a serious health problem?

Further Reading / Supplemental Links

- http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookEXCRETE
- http://kidney.niddk.nih.gov/kudiseases/pubs/yourkidneys
- http://en.wikipedia.org/wiki

Vocabulary

antidiuretic hormone (ADH) Hormone that controls the absorption of water back into blood.

excretion The process of removing wastes from the body.

excretory system The organ system that maintains homeostasis by keeping the correct balance of water and salts in your body; also helps to release wastes from the body.

homeostasis The ability to maintain a stable internal environment despite external changes.

kidney Organ that filters and cleans the blood and forms urine; also maintains the volume of body fluids, maintains the balance of salt ions in body fluids, and excretes harmful metabolic by-products such as urea, ammonia, and uric acid.

kidney dialysis The process of artificially filtering the blood of wastes; a patient's blood is sent through a filter that removes waste products and the clean blood is returned to the body.

kidney failure When the kidneys are not able to regulate water and chemicals in the body or remove waste products from the blood.

kidney stone "Stones" formed when certain mineral wastes in urine crystallize; may be found anywhere in the urinary system.

nephron Tiny, tube-shaped filtering unit found inside each kidney.

urea A nitrogen-containing molecule that is made when foods containing protein, such as meat, poultry, and certain vegetables, are broken down in the body.

ureter Tube-shaped structure that brings urine from the kidneys to the urinary bladder.

urethra Structure through urine leaves the body.

urinary bladder Organ that collects the urine which comes from the kidneys.

urinary system The organ system that makes, stores, and gets rid of urine.

urinary tract infection (UTI) Bacterial infections of any part of the urinary tract.

urination The process of releasing urine from the body.

urine A liquid that is formed by the kidneys when they filter wastes from the blood; contains mostly water and also dissolved salts and nitrogen-containing molecules.

Points to Consider

- Next we turn our attention to the nervous system. What do you think the nervous system is? What do you think it does?

Image Sources

(1) Piotr Michał Jaworski. *PioM.png* . GNU-FDL.

(2) J.C. Rojas. http://www.flickr.com/photos/jcrojas/523383835/. CC-BY-SA 2.5.

(3) http://kidney.niddk.nih.gov/kudiseases/pubs/yourkidneys/. National Kidney and Urologic Diseases Information Clearinghouse encourages users of this publication to duplicate and distribute as many copies as desired..

(4) http://en.wikipedia.org/wiki/Image:Pertussis.jpg. Public Domain.

(5) http://www.cdc.gov/flu/images/CoverCgh-Sch-view.gif. (b)Public Domain.

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(7) http://commons.wikimedia.org/wiki/File:Spitkid.jpg. Public Domain.

(8) http://commons.wikimedia.org/wiki/File:Illu_urinary_system.jpg. Public Domain.

(9) http://en.wikipedia.org/wiki/File:TB_poster.jpg. Public Domain.

(10) David Shankbone. http://commons.wikimedia.org/wiki/File:Air_bubbles_in_a_pool_as_a_man_surfaces_for_air.jpg. CC-BY-SA 3.0.

(11) http://training.seer.cancer.gov/anatomy/respiratory/passages/bronchi.html.

(12) Patrick J. Lynch and C. Carl Jaffe, M.D.. http://commons.wikimedia.org/wiki/File:Bronchial_anatomy.jpg. CC-BY-SA 2.0.

(13) NIH. http://kidney.niddk.nih.gov/kudiseases/pubs/yourkidneys/. Public Domain.

(14) Theresa Knott. *system.svg* . CC-BY-SA 2.5.

(15) Robert R. Wal. http://en.wikipedia.org/wiki/Image:Nefrolit.jpg. Public Domain.

(16) http://commons.wikimedia.org/wiki/File:Influenza_virus_particle_color.jpg. Public Domain.

(17) Mr TS88 Duel. http://commons.wikimedia.org/wiki/File:Alveoli.svg. GNU-FDL, CC-BY-2.5.

(18) http://commons.wikimedia.org/wiki/File:Centrilobular_emphysema_865_lores.jpg. (b)Public Domain, COPD.

Chapter 20

Controlling the Body

20.1 Lesson 20.1: Nervous System

Lesson Objectives

- Identify the functions of the nervous system.
- Describe neurons and explain how they carry nerve impulses.
- Describe the structures of the central nervous system.
- Outline the divisions of the peripheral nervous system.

Check Your Understanding

- If groups of cells are called tissues and groups of tissues are called organs, what are groups of organs called?
- What are examples of human organ systems?
- Which organ system controls all the others?

Introduction

Groups of organs called organ systems. Examples of human organ systems are skeletal, digestive, and respiratory systems. The nervous system controls all the others.

Michael was riding his scooter when he hit a hole in the sidewalk and started to lose control. He thought he would fall, but in the blink of an eye, he shifted his weight and regained his balance. His heart was pounding, but at least he didn't get hurt. How was he able to react so quickly? Michael can thank his nervous system for that (**Figure** 20.1).

Figure 20.1: Staying balanced when riding a scooter requires control over the body's muscles; the nervous system controls the muscles and maintains balance. (9)

What Does the Nervous System Do?

The **nervous system** is the body system that controls all the other systems of the body. Controlling muscles and maintaining balance are just two of its roles. The nervous system also lets you:

- Senses your surroundings with your eyes and other sense organs.
- Senses your internal environment, including temperature and pH.
- Controls your internal body systems and keeps them in balance.
- Prepares your body to fight or flee in emergency situations.
- Thinks, learns, remembers, and uses language.

The nervous system works by sending and receiving electrical messages. The messages are carried by nerves throughout the body. For example, when Michael started to fall off his scooter, his nervous system sensed that he was losing his balance. It responded by sending messages to muscles throughout his body. Some muscles tightened while others relaxed. As a result, Michael's body became balanced again. How did his nervous system do all that in just a split second? To answer this question, you need to know how the nervous system carries messages.

Neurons and Nerve Impulses

The nervous system is made up of nerves. A **nerve** is a bundle of individual nerve cells. A nerve cell that carries messages is called a **neuron** (**Figure** 20.2). The messages carried by neurons are referred to as **nerve impulses.** Nerve impulses are able to travel very quickly

because they are electrical impulses. Think about flipping on a light switch when you enter a room. When you flip the switch, it closes an electrical circuit. With the circuit closed, electricity can flow to the light through wires inside the walls. The electricity may have to travel many meters to reach the light, but the light still comes on as soon as you flip the switch. Nerve impulses travel equally fast through the network of nerves inside the body.

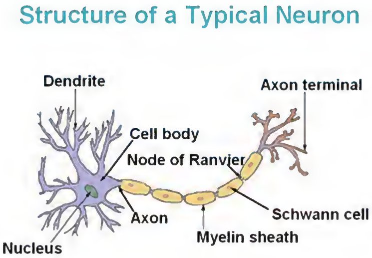

Figure 20.2: The axons of many neurons, like the one shown here, are covered with a fatty layer called myelin sheath that insulates the axon like the plastic covering on an electrical wire, and allowing nerve impulses to travel faster along the axon. (19)

What Does a Neuron Look Like?

A neuron has a special shape that lets it pass signals from one cell to another. As shown in **Figure 2**, a neuron has three main parts: cell body, dendrites, and axons. The **cell body** contains the nucleus and other organelles. Dendrites and axons project from the cell body. **Dendrites** receive nerve impulses from other cells, and **axons** pass the nerve impulses on to other cells. A single neuron may have thousands of dendrites and axons, so it can communicate with thousands of other cells.

Types of Neurons

Neurons are usually classified based on the role they play in the body. Two types of neurons are sensory neurons and motor neurons.

- **Sensory neurons** carry nerve impulses from sense organs and internal organs to the central nervous system (see below).

- **Motor neurons** carry nerve impulses from the central nervous system to internal organs, glands, and muscles.

Both types of neurons work together. Sensory neurons carry information about conditions inside or outside the body to the central nervous system. The central nervous system processes the information and sends message through motor neurons telling the body how to respond to the information.

The Synapse

The place where the axon of one neuron meets the dendrite of another is called a **synapse**. Synapses are also found between neurons and other type of cells, such as muscle cells. The axon of the sending neuron doesn't actually touch the dendrite of the receiving neuron. There is a tiny gap between them, as shown in **Figure** 20.3.

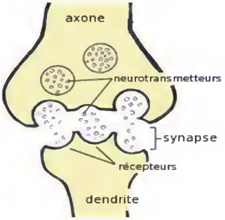

Figure 20.3: This diagram shows a synapse between neurons; when a nerve impulse arrives at the tip of the axon, neurotransmitters are released and travel to the receiving dendrite, carrying the nerve impulse from one neuron to the next. (11)

When a nerve impulse reaches the tip of an axon, the axon releases chemicals called **neurotransmitters.** These chemicals travel across the gap between the axon and the dendrite of the next neuron. They bind to the membrane of the dendrite. This triggers a nerve impulse in the receiving neuron. Did you ever watch a relay race? After the first runner races, she passes the baton to the next runner, who takes over. Neurons are a little like relay runners. Instead of a baton, they pass neurotransmitters to the next neuron. Examples of neurotransmitters include serotonin, dopamine, and adrenaline.

You can watch an animation of nerve impulses and neurotransmitters at: http://www.mind.ilstu.edu/curriculum/neurons_intro/neurons_intro.php

Some people have low levels of the neurotransmitter serotonin in their brain. Scientists think that this is one cause of depression. Medications called antidepressants help bring serotonin levels back to normal. For many people with depression, antidepressants control the symptoms of their depression and help them lead happy, productive lives.

Central Nervous System

The **central nervous system (CNS)** is the largest part of the nervous system. As shown in **Figure** 20.4, it includes the brain and the spinal cord. The brain is protected within the bony skull. The spinal cord is protected within the bones of the spine, which are called vertebrae.

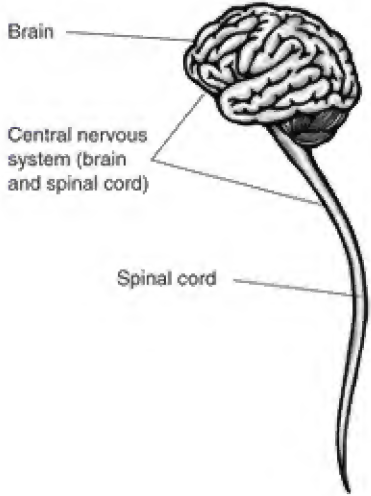

Figure 20.4: The brain and spinal cord make up the central nervous system. (26)

The Brain

What weighs about 3 pounds (1.5 kilograms) and contains up to 100 billion cells? The answer is the human brain. The **brain** is the control center of the nervous system. It's like the pilot of a plane. It tells other parts of the nervous system what to do. The brain is also the most complex organ in the body. Each of its 100 billion neurons has synapses connecting it with thousands of other neurons. All those neurons use a lot of energy. In fact, the adult brain uses almost a quarter of the total energy used by the body. The developing brain of a baby uses an even greater percentage of the body's total energy.

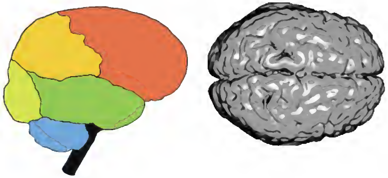

Figure 20.5: Side view of the brain; find the location of the three major parts of the brain, noting that the cerebrum is divided into four lobes at the upper portion of the brain: the frontal, parietal, temporal, and occipital lobes(Left).Top view of the brain and cerebrum; divided from front to back into two halves, these are the right and left hemispheres(Right). (30)

The brain is the organ that lets us interpret what we see, hear, or sense in other ways. It also allows us to learn, think, remember, and use language. The brain controls all of our internal body processes and external movements, as well. As shown in **Figure** 20.5, the brain consists of three main parts:

- The **cerebrum** is the largest part of the brain. It lies on top of the brainstem (discussed below). The cerebrum controls functions that we are aware of, such as problem-solving and speech. It also controls voluntary movements, like waving to a friend. Whether you are doing your homework or jumping hurdles, you are using your cerebrum.
- The **cerebellum** is the next largest part of the brain. It lies under the cerebrum and behind the brain stem. The cerebellum controls body position, coordination, and balance. Whether you are riding a bicycle or writing with a pen, you are using your cerebellum.
- The **brain stem** is the smallest of the three main parts of the brain. It lies directly under the cerebrum. The brain stem controls basic body functions such as breathing, heartbeat, and digestion. The brain stem also carries information back and forth between the cerebrum and spinal cord.

The cerebrum is divided into a right and left half, as shown in **Figure** 20.5. Each half of the cerebrum is called a **hemisphere.** The two hemispheres are connected by a thick bundle of axons called the corpus callosum. It lies deep inside the brain and carries messages back and forth between the two hemispheres. The right hemisphere controls the left side of the body, and the left hemisphere controls the right side of the body. This would be impossible without the corpus callosum.

> Dr. Jill Bolte Taylor is a brain scientist. At the age of 37, she suffered massive brain damage when blood vessels burst inside her brain. It took Dr. Taylor almost ten years to recover from the damage to her brain. She had to relearn even basic skills, like walking and talking. To share her story of recovery with others, Dr. Taylor wrote a popular book describing what she went through. Her story gave other people so much inspiration that *Time Magazine* named her one of the world's 100 most influential people in 2008.

Each hemisphere of the cerebrum is divided into four parts called lobes. The four lobes are the frontal, parietal, temporal, and occipital lobes (**Figure** 20.5). Each lobe has different functions. Some of the functions are listed in **Table** (20.1).

Table 20.1: **Cerebral Lobes and Their Functions**

Lobe	Main Function(s)
Frontal	Speech, thinking, touch
Parietal	Speech, taste, reading
Temporal	Hearing, smell
Occipital	Sight

The Spinal Cord

The **spinal cord** is a long, tube-shaped bundle of neurons. It runs from the brain stem to the lower back. The main job of the spinal cord is to carry nerve impulses back and forth between the body and brain. The spinal cord is like a two-way highway. Messages about the body, both inside and out, pass through the spinal cord to the brain. Messages from the brain instructing the body how to respond pass through the spinal cord to the body.

Peripheral Nervous System

The **peripheral nervous system (PNS)** consists of all the nerves of the body that lie outside the central nervous system. The network of nerves that make up the peripheral system is shown in **Figure** 20.6. They include nerves of the hands, arms, feet, legs, and

trunk. They also include nerves of the scalp, neck, and face. Nerves that supply the internal organs and glands are part of the peripheral nervous system, as well.

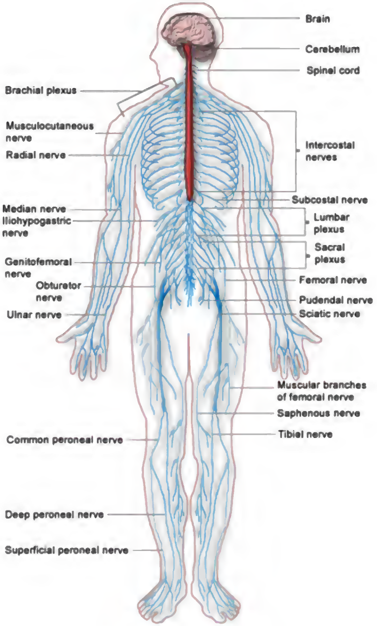

Figure 20.6: The blue lines in this drawing represent nerves of the peripheral nervous system; every peripheral nerve is connected directly or indirectly to the spinal cord. (39)

The peripheral nervous system is divided into two parts: the sensory division and the motor division. How these divisions of the peripheral nervous system are related to the rest of the nervous system is shown in **Figure** 20.7. Refer to the figure as you read more about the

peripheral nervous system below.

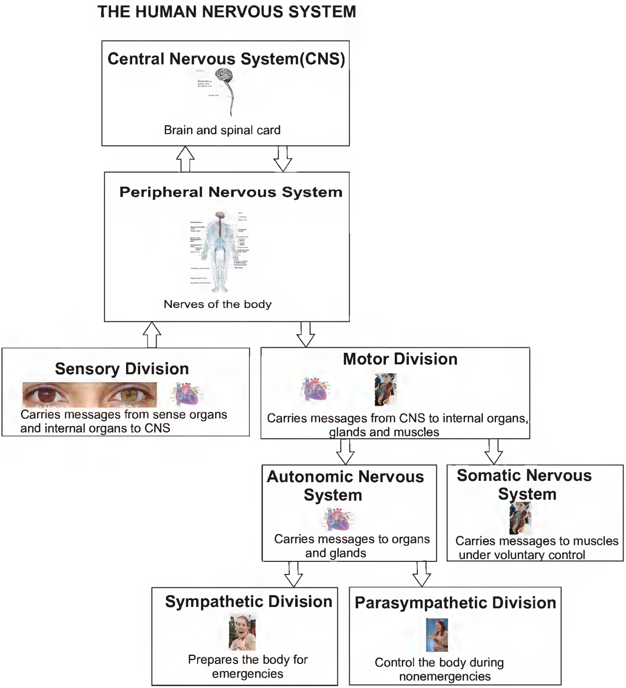

Figure 20.7: The central nervous system interprets messages from sense organs and internal organs and the motor division sends messages to internal organs, glands, and muscles. (34)

The **sensory division** carries messages from sense organs and internal organs to the central

nervous system. Human beings have several senses. They include sight, hearing, balance, touch, taste, and smell. We have special sense organs for each of these senses. Sensory neurons in each sense organ detect a certain type of stimulus, or input. For example, sensory neurons in the eyes detect light, and sensory neurons in the skin detect touch.

Other animals have senses that humans don't have. For example, sharks and some other fish can detect weak electric currents. Many animals can detect magnetism. Detecting magnetism is like having an internal compass. It helps the animals find their way from place to place. For example, birds use their sense of magnetism to guide their seasonal migrations.

Our sense organs detect sensations, but they don't tell us what we are sensing. For example, when you inhale chemicals given off by baking cookies, your nose doesn't tell you that you are smelling cookies. That's your brain's job. The sense organs send messages about sights, smells, and other stimuli to the brain (**Figure** 20.8). The brain then interprets the messages. A particular area of the brain interprets information from each sense organ (**Figure** 20.5). For example, information from the nose is interpreted by the temporal lobe of the cerebrum.

Figure 20.8: Remember which lobes of the cerebrum interpret messages from each of the senses; decide which senses would be stimulated by these raspberries or look back at **Table** (20.1) for clues. (28)

The **motor division** of the peripheral system carries messages from the central nervous system to internal organs and muscles. As shown in **Figure** 20.7, the motor division is also divided into two parts: the somatic nervous system and the autonomic nervous system. The **somatic nervous system** carries messages that control body movements. It's responsible for activities that are under your control, such as waving your hand or kicking a ball. The

girl in **Figure** 20.9 is using her somatic nervous system to control the muscles needed to play the violin. Her brain sends commands to motor neurons that move her hands so she can play. Without the commands from her brain, she wouldn't be able to move her hands and play the violin.

Figure 20.9: This girl's central nervous is controlling the movements of her hands and arms as she plays the violin; her brain is sending commands to her somatic nervous system, which controls the muscles of her hands and arms. (2)

The **autonomic nervous system** carries nerve impulses to internal organs. It is responsible for activities that are not under your control, such as sweating and digesting food. The autonomic nervous system has two divisions:

- The **sympathetic division** controls internal organs and glands during emergencies. It prepares the body for fight or flight (**Figure** 20.10). For example, it increases the heart rate and the flow of blood to the legs.
- The **parasympathetic division** controls internal organs and glands the rest of the time. It manages routine functions such as digestion, heartbeat, and breathing under normal conditions.

Remember Michael on his scooter at the start of this lesson? Why was his heart pounding after he regained his balance? The answer is his autonomic nervous system. The sympathetic

Figure 20.10: The woman pictured here is just pretending to be frightened, but assuming that she really was scared, think of which division of the autonomic nervous system would prepare her body for an emergency. (40)

division prepared him to deal with the emergency by increasing his heart rate. The fact that this happened in the blink of an eye shows how amazing the nervous system is.

Lesson Summary

- The nervous system controls all the other systems of the body.
- Neurons are nerve cells that carry nerve impulses. The central nervous system is made up of the brain and spinal cord.
- The peripheral nervous system consists of all the rest of the nerves in the body.

Review Questions

1. List three functions of the nervous system.
2. Describe a neuron and identify its three main parts.
3. What structures make up the central nervous system?
4. Name the lobes of the cerebrum and state one function of each lobe.
5. What are the two major divisions of the peripheral nervous system? **(Beginning**

6. Explain how one neuron transmits a nerve impulse to another neuron. **(Intermediate**
7. Compare and contrast the three main parts of the brain.
8. Why is the spinal cord like a two-way highway?
9. A baby girl sees a toy and reaches out to grab it. Describe the path of messages through the baby's nervous system, from her eyes to her hand.
10. Assume you are so startled by a sudden loud noise that your heart starts pounding fast. Explain what controls your reaction to the loud sound.

Further Reading / Supplemental Links

CK12 High School *Biology*, Chapter 35 http://biology.clc.uc.edu/Courses/bio105/nervous.htm.

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Chris Hawkes. *The Human Body: Uncovering Science.* Firefly Books, 2006.

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H.P. Newquist. *The Great Brain Book: An Inside Look at the Inside of Your Head.* Scholastic Nonfiction, 2005.

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- http://training.seer.cancer.gov/module_anatomy/unit5_1_nerve_functions.html
- http://www.pelagic.org/overview/articles/sixsense.html http://www.pbs.org/wgbh/nova/magnetic/animals.html; http://www.pelagic.org/overview/articles/sixsense.html
- http://en.wikipedia.org/wiki/Brain_stem http://en.wikipedia.org/wiki/Autonomic_nervous_system; http://en.wikipedia.org/wiki/Brain_stem

Vocabulary

autonomic nervous system Part of the motor division that carries nerve impulses to internal organs and glands.

axon Part of a neuron that receives nerve impulses from the cell body and passes them on to other cells.

brain Control center of the nervous system that is located inside the skull.

brain stem Part of the brain that controls basic body functions such as breathing, heartbeat, and digestion.

cell body Part of a neuron that contains the nucleus and other organelles.

central nervous system Part of the nervous system that includes the brain and spinal cord.

cerebellum Part of the brain that controls body position, coordination, and balance.

cerebrum Part of the brain that controls awareness and voluntary movements.

dendrite Part of a neuron that receives nerve impulses from other cells and passes them on to the cell body.

hemisphere One of the two halves of the cerebrum.

motor division Division of the peripheral nervous system that carries messages from the central nervous system to internal organs, glands, and muscles.

motor neuron Neuron that carries nerve impulses from the central nervous system to internal organs, glands, or muscles.

nerve Bundle of individual nerve cells.

nerve impulse Electrical signal that is transmitted by neurons.

nervous system Body system that controls all the other systems of the body.

neuron Nerve cell that carries electrical messages.

neurotransmitter Chemical that carries nerve impulses from the axon of one neuron to the dendrite of the next neuron.

parasympathetic division Division of the autonomic nervous system that controls body processes under nonemergency conditions.

peripheral nervous system All the nerves of the body that lie outside the central nervous system.

sensory division Division of the peripheral nervous system that carries messages from the sense organs and internal organs to the central nervous system.

sensory neuron Neuron that carries nerve impulses from sense organs or internal organs to the central nervous system.

somatic nervous system Part of the motor division that carries nerve impulses to muscles that control voluntary body movements.

spinal cord Long, tube-shaped bundle of neurons that carry nerve impulses back and forth between the body and brain.

sympathetic division Division of the autonomic nervous system that prepares the body for fight or flight in emergencies.

synapse Place where the axon of one neuron meets the dendrite of another neuron.

Points to Consider

- The sensory division of the peripheral nervous system carries messages from sense organs to the central nervous system. What are some examples of sense organs?

- Do you know how sense organs work? For example, do you know how your eyes sense light?

20.2 Lesson 20.2: Eyes and Vision

Lesson Objectives

- Describe how humans see and explain why vision is important.
- Explain how the eye works to produce images.
- Describe the nature of light.
- Explain how lenses correct vision problems.

Check Your Understanding

- What are some ways that people use their eyes?
- Which part of the nervous system carries messages from the eyes to the central nervous system?
- Which part of the brain interprets messages from the eyes?

Introduction

Think about all the ways that students use their sense of sight during a typical school day. As soon as they open their eyes in the morning, they may look at the clock to see what time it is. Then, they might look out the window to see what the weather is like. They probably look in a mirror to comb their hair. In school, they use their eyes to read the board, their textbooks, and the expressions on their friend's faces. After school, they may keep their eye on the ball while playing basketball (**Figure** 20.11). Then they might read their homework assignment and the text messages from their friends. If you aren't visually impaired, you probably use your sense of sight in all of these ways, as well. In fact, you may depend on your sight so much that you have a hard time thinking of anything you do without it, except sleep. Why is sight so important?

Figure 20.11: All eyes are on the ball in this basketball game; think about how we use the sense of sight in other games. (15)

The Nature of Human Vision

Sight, or **vision,** is the ability to see light. It depends on the eyes detecting light and forming images. It also depends on the brain making sense of the images, so we know what we are seeing. Human beings—and other primates—depend on vision more than many other animals. It's not surprising, then, that we have a better sense of vision than many other animals. Not only can we normally see both distant and close-up objects clearly. We can also see in three dimensions and in color.

Seeing in Three Dimensions

Did you ever use 3-D glasses to watch a movie, like the boy in **Figure** 20.12? If you did, then you know that the glasses make people and objects in the movie appear to jump out of the screen. They make images on the flat movie screen seem more realistic because they give them depth. That's the difference between seeing things in two dimensions and three dimensions.

Figure 20.12: This boy is wearing 3-D glasses; when you look at objects and people in the real world, your eyes automatically see in three dimensions. (37)

We are able to see in three dimensions because we have two eyes facing the same direction but a few inches apart. As a result, we see objects and people with both eyes at the same time, but from slightly different angles. Hold up a finger a few inches away from your face, and look at it first with one eye and then with the other. You'll notice that your finger appears to move against the background. Now hold up your finger at arm's length, and look at it with one eye and then the other. Your finger seems to move less against the background than it did when it was closer. Although you aren't aware of it, your brain constantly uses such differences to determine the distance of objects.

Seeing in Color

For animals like us that see in color, it may be hard to imagine a world that appears to be mainly shades of gray. You can get an idea of how many other animals see the world by looking at a black-and-white picture of colorful objects. For example, look at the apples on the tree **Figure** 20.13. In the top picture, they appear in color, the way you would normally see them. In the bottom picture they appear without color, in shades of gray (**Figure** 20.14).

Figure 20.13: Humans with color vision see the apples on this tree; the bright red color of the apples stands out clearly from the green background of leaves. (4)

Figure 20.14: Dogs and cats would see the green and red colors as shades of gray; they are able to see blue, but red and green appear the same to them. (24)

Evolution and Primate Vision

Why do you think primates, which include humans, evolved the ability to see in three dimensions and in color? To answer that question, you need to know a little about primate evolution. Millions of years ago, primate ancestors lived in trees. To move about in the trees, they needed to be able to judge how far away the next branch was. Otherwise, they might have a dangerous fall. Being able see in depth was important. It was an adaptation that would help tree-living primates survive.

Primate ancestors also mainly ate fruit. They needed to be able to spot colored fruits among the dense leafy background of the trees (**Figure** 20.15). They also had to be able to judge which fruits were ripe and which were still green. Ripe fruits are usually red, orange, yellow, or purple. Being able to see in color was important for finding food. It was an adaptation that would help fruit-eating primates survive.

Figure 20.15: With color vision, you can tell which cherries in this picture are ripe, because cherries turn red as they ripen. (12)

Knowing about primate evolution helps explain *why* we see the way we do. However, it doesn't explain *how* we see as we do. What allows us to see in three dimensions and in color? To answer that question, you need to know how the eye works.

How the Eye Works

The function of the eye is to focus light. The parts of the eye, shown in **Figure** 20.16, suit it for that function. Follow the path of light through the eye as you read about it below.

You can also watch an animation of the eye at http://pennhealth.com/health_info/animationplayer/seeing.html.

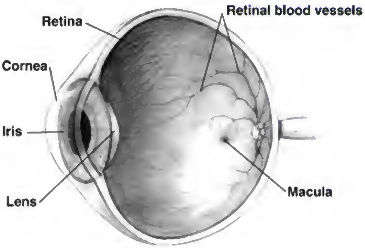

Figure 20.16: The human eye is a complex structure that detects light; the light passes through the cornea, pupil, and lens, and is focused on the retina. (20)

Vision involves detecting and focusing light from people and objects. First, light passes through the **cornea** of the eye. The cornea is a clear, protective covering on the outside of the eye. Next, light passes through the pupil. The **pupil** is a black opening in the eye that lets light enter the eye. Surrounding the pupil is the **iris,** more commonly brown, blue, grey, or green.

After passing into the eye through the pupil, light passes next through the lens. Like a hand lens, the **lens** of the eye is a clear, curved structure. Along with the cornea, the lens helps focus light at the back of the eye. This is shown in **Figure** 20.17. The lens must bend light from nearby objects more than it bends light from distant objects. The lens changes shape to bend the light by just the right amount to bring objects into focus.

The lens focuses light on the **retina,** which covers the back of the inside of the eye. The retina consists of light-sensing cells called rods and cones. Rods let us see in dim light. Cones let us detect light of different colors. When light strikes rods and cones, it causes chemical changes. The chemical changes start nerve impulses. The nerve impulses travel to the brain through the optic nerve (**Figure** 20.16). The brain interprets the nerve impulses and tells you what you are seeing. You know that the eyes sense light. But do know what light is? You need to understand the nature of light to fully understand vision.

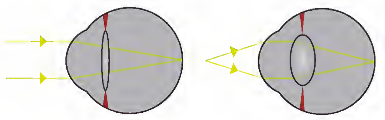

Figure 20.17: Light from objects at different distances is focused by the lens of the eye; muscles in the eye control the shape of the lens so the light is focused on the back of the eye no matter how far the object is from the lens. (17)

The Nature of Light

Visible light is a type of electromagnetic (EM) radiation. It's the only type of EM radiation that can be detected by the human eye. To be visible to humans, EM radiation has to travel in waves of certain wavelengths. Wavelength is the distance from any point on one wave to the same point on the next wave. The different types of electromagnetic radiation are shown in **Figure** 20.18. Just a small part of the full range of EM radiation is visible to the human eye.

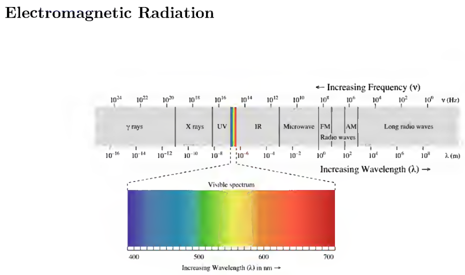

Figure 20.18: This diagram shows the wavelengths of electromagnetic radiation, from shortest (extreme left) to longest (extreme right); the human eye can detect only visible light, which falls in a narrow range of wavelengths, but the eyes of some animals can detect radiation of different wavelengths; bees can see ultraviolet radiation. (16)

Colors of Light

Visible light from the sun is colorless. However, if you bend visible light by passing it through a prism, it produces a "rainbow" of light of different colors (**Figure** 20.19). Why does this happen? Different colors of visible light have slightly different wavelengths. Light of different wavelengths bends by different degrees when it passes through a prism. This separates visible light into all of its colors.

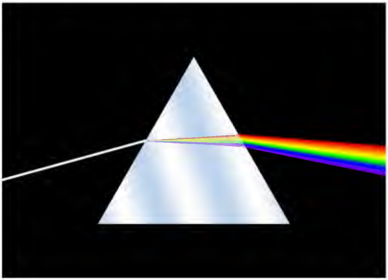

Figure 20.19: A prism bends white light to create a "rainbow" of red, orange, yellow, green, blue, indigo, and violet light. (31)

Light and Vision

Except for objects that give off their own light, we don't see things just because light strikes them. We see things because light strikes them and then reflects, or bounces back, from their surface. What we see is the reflected light.

Some things reflect all the light that strikes them. These things appear white. Some things do not reflect any light. Instead, they absorb all the light that strikes them. These things appear black. Other things, like the beads in **Figure** 20.20, reflect just one wavelength of light. Whatever wavelength they reflect is the color we see. For example, beads that reflect only red light look red to us.

Lenses and Vision Correction

You probably know people that need eyeglasses or contact lenses to see clearly. Maybe you need them yourself. Lenses are used to correct vision problems. Two of the most common

Figure 20.20: These plastic beads reflect light of different wavelengths, so they appear to be different colors. (3)

vision problems are myopia and hyperopia. To watch an animation that shows how these two vision problems occur and how they can be corrected, go to http://pennhealth.com/health_info/animationplayer/seeing.html.

Myopia

Myopia is also called nearsightedness. It affects about one third of people. People with myopia can see nearby objects clearly, but distant objects appear blurry. How a person with myopia might see two boys that are a few meters away is shown in **Figure** 20.21.

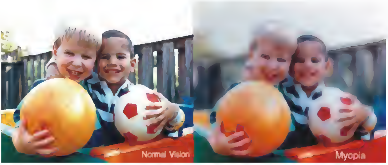

Figure 20.21: This is how a person with normal vision sees the two boys(Left)Normal Vision (Right)Myopia. (8)

In myopia, the eye is too long. As shown in **Figure** 20.22, this results in images being focused in front of the retina. Myopia is corrected with a concave lens, which curves inward like the inside of a bowl. The lens changes the focus so images fall on the retina as they should.

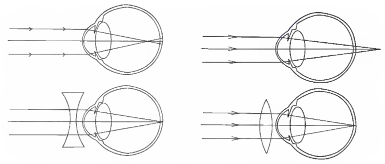

Figure 20.22: The eye of a person with myopia is longer than normal and as a result, images are focused in front of the retina (top); concave lens is used to correct myopia to help focus images on the retina (bottom)(Left)Normal Vision (Right)Myopia. (7)

Hyperopia

Hyperopia is also called farsightedness. It affects about one fourth of people. People with hyperopia can see distant objects clearly, but nearby objects appear blurry. In hyperopia, the eye is too short. As shown in Figure 11b, this results in images being focused in back of the retina. Hyperopia is corrected with a convex lens, which curves outward like the outside of a bowl. The lens changes the focus so images fall on the retina as they should.

In addition to lenses, many cases of myopia and hyperopia can be corrected with surgery. For example, a procedure called LASIK uses a laser to permanently change the shape of the cornea so light is correctly focused on the retina.

Lesson Summary

- Humans can normally see both distant and close-up objects clearly, and we also see in three dimensions and color.
- Light entering the eye is focused by the lens on the retina, which sends messages to the brain through the optic nerve.
- Visible light is electromagnetic radiation that can be detected by the human eye.
- Vision problems such as myopia and hyperopia can be corrected with lenses that help focus light on the retina.

Further Reading / Supplemental Links

CK12 High School Biology, Chapter 35 http://www.fda.gov/CDRH/LASIK

- Body Atlas. *Nerves, Brain and Senses.* Ticktock Media Ltd., 2004.
- Donald B. Light. *The Senses.* Chelsea House Publications, 2004.
- Christopher Sloan. *The Human Story: Our Evolution from Prehistoric Ancestors to Today.* National Geographic Children's Books, 2004.
- http://www.veterinaryvision.com/See.htm
- http://en.wikipedia.org/wiki

Review Questions

1. What is vision?
2. Describe the lens of the eye and what it does.
3. What happens when light is focused on the retina of the eye?
4. Describe visible light.
5. What is hyperopia?
6. Explain how humans can see in three dimensions.
7. Why were depth perception and color vision important for early primates?
8. Black is sometimes defined as the absence of light. Why?
9. Assume you see a bright red apple. Why does the apple look red?
10. What causes myopia, and what type of lens corrects it?

Vocabulary

cornea Clear, protective covering on the outside of the eye that helps focus light.

hyperopia Vision problem in which distant objects are clear but nearby objects look blurry; also called farsightedness.

iris Colored structure at the front of the eye.

lens Clear, curved structure in the eye that focuses light on the retina.

myopia Vision problem in which nearby objects are clear but distant objects look blurry; also called nearsightedness.

pupil Black opening in the iris that lets light enter the eye.

retina Layer of light-sensing cells that covers the back of the eye.

visible light Electromagnetic radiation that humans can detect with their eyes.

vision Ability to see light.

Points to Consider

- The sense of sight is important to humans and other animals, but other senses may be equally important. What are some of our other senses?

- Why are these other senses important to us? For example, what are some ways we depend on our sense of hearing?

20.3 Lesson 20.3: Other Senses

Lesson Objectives

- Explain how the ears hear and help maintain balance.
- Outline how we sense pressure, temperature, and pain.
- Describe how we identify different tastes and smells.
- Explain why hearing, balance, touch, taste, and smell are important.

Check Your Understanding

- What is the role of the nervous system?
- How do signals ("messages") get from one area of the body to the brain?

Introduction

Imagine walking through the fruit market shown in **Figure** 20.23. Your sense of sight would be stimulated by all the brightly colored fruits. But your other senses would be stimulated, too. You would hear the noisy bustle of the market. As you checked to see if a piece of fruit was firm, you would feel its smooth skin. If you tried a sample of the fruit, you would taste its juicy sweetness and smell its appetizing aroma. Clearly, a market like this is a feast for all of the senses. In this lesson, you will read how your nervous system senses the sound, feel, taste, and smell of a market like this—and of everything else around you.

Figure 20.23: This outdoor fruit market stimulates all the senses—sight, sound, smell, taste, and touch. (25)

Hearing and Balance

What do listening to music and riding a bike have in common? It might surprise you to learn that both activities depend on your ears. The **ears** are sense organs that detect sound. They also sense the position of the body and help maintain balance.

Hearing

Hearing is the ability to sense sound. Sound travels through the air in waves, much like the waves you see in the water in **Figure** 20.24 and the light waves described in Lesson 2. Sound waves in air cause vibrations inside the ears. The ears detect the vibrations.

Figure 20.24: Sound waves travel through the air in all directions away from a sound like waves traveling through water away from where a pebble was dropped. (13)

What the human ear looks like is shown in **Figure** 20.25. As you read about it below, trace the path of sound waves through the ear. You can also see an animation of the ear sensing sound at http://www.sumanasinc.com/webcontent/animations/content/ sound-transduction.html.

Assume a car horn blows in the distance. Sound waves spread through the air from the horn. Some of the sound waves reach your ear. The steps below show what happens next. They

explain how your ears sense the sound. Each numbered step refers to a structure with the same number in **Figure** 20.25 and **Table** (20.2).

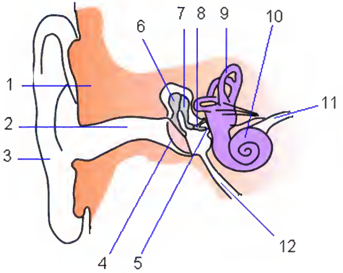

Figure 20.25: Read the names of the parts of the ear in the key (Table 20.2), then find each of the parts in the diagram, referring to the diagram as you read about the parts of the ear. (36)

Table 20.2:

Number in diagram	Part of the ear
1	pinna
2	ear canal
3	eardrum
4	hammer
5	anvil
6	stirrup
7	oval window
8	cochlea
9	auditory nerve
10	semicircular canals

1. The sound waves are gathered by the **pinna,** or outer ear. This is the part of the ear you can see.
2. The sound waves are channeled into the **ear canal.** This is a tube-shaped opening in

the ear.

3. At the end of the ear canal, the sound waves strike the **eardrum.** This is a thin membrane that vibrates like the head of drum when sound waves hit it.
4. The vibrations pass from the eardrum to the **hammer.** This is the first of three tiny bones that pass vibrations through the ear.
5. The hammer passes the vibrations to the **anvil,** the second tiny bone that passes vibrations through the ear.
6. The anvil passes the vibrations to the **stirrup,** the third tiny bone that passes vibrations.
7. From the stirrup, the vibrations pass to the **oval window.** This is another membrane like the eardrum.
8. The oval window passes the vibrations to the **cochlea.** The cochlea is filled with liquid that moves when the vibrations pass through, like the waves in water when you drop a pebble into a pond. Tiny hair cells line the cochlea and bend when the liquid moves. When the hair cells bend, they release neurotransmitters.
9. The neurotransmitters trigger nerve impulses that travel to the brain through the **auditory nerve.** The brain interprets the sound and "tells" you what you are hearing.

No doubt you've been warned that listening to loud music or other loud sounds can damage your hearing. It's true. In fact, repeated exposure to loud sounds is the most common cause of hearing loss. The reason? Very loud sounds can kill the tiny hair cells lining the cochlea. The hair cells do not generally grow back once they are destroyed, so this type of hearing loss is permanent. You can protect your hearing by avoiding loud sounds or wearing earplugs or other ear protectors.

Balance

Did you ever try to stand on one foot with your eyes closed? Try it and see what happens, but be careful! It's harder to keep your balance when you can't see. Your eyes obviously play a role in balance. However, your ears play an even bigger role. The gymnast in **Figure** 20.26 may not realize it, but her ears—along with her cerebellum—are primarily responsible for her ability to perform on the balance beam.

The parts of the ears involved in balance are the **semicircular canals.** In **Figure** 20.25, the semicircular canals are the structures numbered 10. The canals contain liquid, and are like the bottle of water in **Figure** 20.27. When the bottle tips, the water surface moves up and down the sides of the bottle. When the body tips, the liquid in the semicircular canals moves up and down the sides of the canals. Tiny hair cells line the semicircular canals. Movement of the liquid inside the canals triggers the hair cells to send nerve impulses. The nerve impulses travel to the cerebellum in the brain. In response, the cerebellum sends commands to muscles to contract or relax so the body stays balanced.

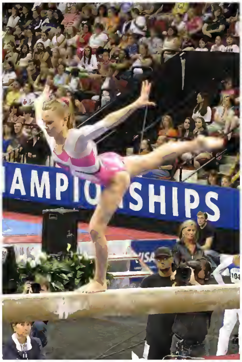

Figure 20.26: This gymnast is using the semicircular canals in her ears, along with the cerebellum in her brain, to help keep her balance on the balance beam. (29)

Figure 20.27: This bottle of water models the semicircular canals in your ears; when you tip the bottle, the water moves up or down the sides of the bottle; when you tip your head, the liquid inside the semicircular canals moves up and down the sides of the canals; tiny hair cells lining the canals detect the movement of liquid and send messages to the brain. (21)

Touch

When you look at the prickly cactus in **Figure** 20.28, does the word *ouch* come to mind? Touching the cactus would no doubt be painful. **Touch** is the sense of pain, pressure, or temperature. It depends on sensory neurons in the skin. The skin on the palms of the hands, soles of the feet, and face has the most sensory neurons and is especially sensitive to touch. The tongue and lips are very sensitive to touch, as well. Neurons that sense pain are also found inside the body in muscles, joints, and organs. If you have a stomach ache or pain from a sprained ankle, it's because of these internal sensory neurons.

Figure 20.28: The spines on this cactus are like needles, they help keep away animals that might want to eat the cactus. (18)

The following example shows how messages about touch travel from sensory neurons to the brain, as well as how the brain responds to the messages. Suppose you wanted to test the

temperature of the water in a lake before jumping in. You might stick one bare foot in the water. Neurons in the skin on your foot would sense the temperature of the water and send a message about it to your central nervous system The frontal lobe of the cerebrum would process the information. It might decide that the water is really cold and send a message to your muscles to pull your foot out of the water.

In some cases, messages about pain or temperature don't travel all the way to and from the brain. Instead, they travel only as far as the spinal cord, and the spinal cord responds to the messages by giving orders to the muscles. When messages bypass the brain in this way, it forms a **reflex arc**, like the ones shown in **Figures** 20.29, 20.30 and 20.31.

First image:

Second image:

Third Image

Taste and Smell

Your sense of taste is controlled by sensory neurons on your tongue that detect chemicals in food. The neurons are grouped in bundles within **taste buds** (**Figure** 20.32). There are five different types of taste neurons on the tongue. Each type detects a different taste. The tastes are sweet, salty, sour, bitter, and umami, which is a meaty taste. When taste neurons detect chemicals, they send messages to the brain about them. The brain, in turn, decides what tastes you are sensing.

Your sense of smell also involves sensory neurons that detect chemicals. The neurons are found in the nose, and they detect chemicals in the air. Unlike taste neurons, which can detect only five different tastes, the sensory neurons in the nose can detect thousands of different odors.

Have you ever noticed that you lose your sense of taste when your nose is stuffed up? That's because your sense of smell contributes greatly to your ability to taste of food. As you eat, airborne molecules of food chemicals enter your nose. You experience the taste and smell at the same time. Being able to smell as well as taste food greatly increases the number of different tastes you are able to sense. For example, you can use your sense of taste alone to learn that a food is sweet, but you have to use your sense of smell as well to learn that the food tastes like strawberry cheesecake.

Why These Senses Matter

The senses of hearing, balance, touch, taste, and smell enrich our lives each day. The sense of hearing lets us listen to our favorite music. The sense of balance helps us play the sports we like. The sense of touch allows us to use a keyboard to text our friends. The senses of

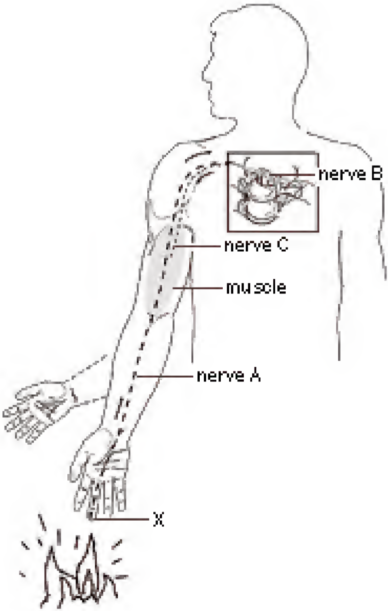

Figure 20.29: Reflex Arc: When you touch something hot, you may jerk your hand away without even thinking about it; the nerve impulse from your hand travels to the spinal cord and the spinal cord sends a message to your muscles to pull back your hand. (23)

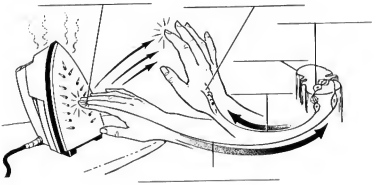

Figure 20.30: Reflex Arc: When you touch something hot, you may jerk your hand away without even thinking about it; the nerve impulse from your hand travels to the spinal cord and the spinal cord sends a message to your muscles to pull back your hand. (5)

Figure 20.31: Reflex Arc: When you touch something hot, you may jerk your hand away without even thinking about it; the nerve impulse from your hand travels to the spinal cord and the spinal cord sends a message to your muscles to pull back your hand. (14)

Figure 20.32: Tiny bumps that cover the tongue contain taste buds, bundles of sensory neurons that allow you to detect different types of tastes, such as sweet and salty tastes. (32)

taste and smell allow us to enjoy the flavor and aroma of our favorite foods.

These five senses not only enrich our life. They also help us sense danger. For example, being able to stay balanced on a icy sidewalk might prevent a nasty fall. Being able to hear a fire alarm could alert us to flee from a burning building. Being able to taste and smell might warn us that food that is spoiled and could make us sick. The sense of smell could also warn us of dangers such as fires and gas leaks.

Being able to feel pain is especially important for preventing injury. It might not seem that pain is a good thing–until you think about what might happen if you couldn't feel pain. For example, what if you couldn't feel a hot iron? You might be badly burned before you realized you were touching it. What if you couldn't feel the pain of a sprained ankle? You might keep using the ankle and make the injury worse.

Lesson Summary

- The ears detect sound waves and help maintain balance. The skin senses pain, pressure, and temperature.

- Sensory cells on the tongue and in the nose detect tastes and smells.

- The senses of hearing, balance, touch, taste, and smell enrich our life and help keep us safe.

Further Reading / Supplemental Links

CK12 High School *Biology,* Chapter 35.

Autumn Libal. *The Ocean Inside: Youth Who Are Deaf and Hard of Hearing.* Mason Crest Publishers, 2007.

Body Atlas. *Nerves, Brain and Senses.* Ticktock Media Ltd., 2004.

Donald B. Light. *The Senses.* Chelsea House Publications, 2004.

Elaine Landau. *The Sense of Touch.* Children's Press, 2008.

- http://en.wikipedia.org/wiki/Taste_buds

Review Questions

1. What are the two main functions of the ears?
2. Which structure in the ear changes sound waves in air to vibrations?

3. What happens after the oval window in the ear passes vibrations to the cochlea?
4. Which parts of the ear sense changes in the body's position?
5. What are the five tastes sensed by neurons on the tongue?
6. Why does death of hair cells in the cochlea cause hearing loss?
7. Explain the statement, "You listen with your ears, but you hear with your brain."
8. How and why do reflex arcs occur?
9. Why is your sense of taste affected when you have a stuffy nose?
10. How could the ability to feel pain help prevent serious injury? Give an example.

Vocabulary

anvil Second of three tiny bones that pass vibrations through the ear.

auditory nerve Nerve that carries nerve impulses generated by sound waves from the ear to the brain.

cochlea Liquid-filled structure in the ear that senses vibrations and generates nerve impulses in response.

ear Sense organ that detects sound.

ear canal Tube-shaped opening in the ear that carries sound waves to the eardrum.

eardrum Membrane in the ear that vibrates when sound waves hit it.

hammer First of three tiny bones that pass vibrations through the ear.

hearing Ability to sense sound.

oval window Membrane in the ear that passes vibrations from the stirrup to the cochlea.

pinna Outer part of the ear that gathers sound waves.

reflex arc Path of nerve impulses that bypass the brain for a quicker response.

semicircular canals Liquid-filled part of the ear that senses changes in position and generates nerve impulses in response.

stirrup Last of three tiny bones that pass vibrations through the ear.

taste buds Tiny bumps on the tongue that contain taste neurons.

touch Sense of pain, pressure, or temperature.

Points to Consider

- Our senses, along with the rest of our nervous system, help us stay safe. At least they do if our nervous system is healthy. But what if the nervous system itself becomes ill or injured? What do you think would happen then? How do you think nervous system problems affect the rest of the body?

20.4 Lesson 20.4: Health of the Nervous System

Lesson Objectives

- Describe diseases of the nervous system.
- Explain how the nervous system can be injured.
- Identify the dangers of alcohol and other drugs.
- List ways to keep the nervous system healthy.

Check Your Understanding

- What is the role of the nervous system?
- What are some of the components of the nervous system?

Introduction

The nervous system controls sensing, feeling, and thinking. It also controls movement and just about every other body function. That's why problems with the nervous system can affect the entire body. Nervous system problems include diseases and injuries. Most nervous system diseases cannot be prevented. However, you can take steps to reduce your risk of nervous system injuries.

Nervous System Diseases

Diseases of the nervous system include brain and spinal cord infections. Other problems of the nervous system range from very serious diseases, such as tumors, to less serious problems, such as tension headaches. Some diseases are present at birth. Others begin during childhood or adulthood.

Central Nervous System Infections

When you think of infections, you probably think of an ear infection or strep throat. You probably don't think of a brain or spinal cord infection. However, bacteria and viruses can infect these organs as well as other parts of the body. Infections of the brain and spinal cord are not very common. But when they happen, they can be very serious. That's why it's important to know their symptoms.

Encephalitis is a brain infection. If you have encephalitis, you are likely to have a fever and headache or feel drowsy and confused. The disease is most often caused by viruses. and the immune system tries to fight off a brain infection, just as it tries to fight off other infections. However, this can do more harm than good. The immune system's response may cause swelling in the brain. With no room to expand, the brain pushes against the skull. This may injure the brain and even cause death. Medicines can help fight some viral infections of the brain. Others just have to run their course.

Meningitis is an infection of the membranes that cover the brain and spinal cord. If you have meningitis, you are likely to have a fever and headache. Another telltale symptom is a stiff neck. Meningitis can be caused by viruses or bacteria. Viral meningitis often clears up on its own after a few days. Bacterial meningitis is much more serious (**Figure** 20.33). It may cause brain damage and death. People with bacterial meningitis need emergency medical treatment. They are usually given antibiotics to kill the bacteria.

Figure 20.33: These bacteria—shown at more than 1,000 times their actual size—are the cause of bacterial meningitis; despite their tiny size, they can cause very serious illness. (10)

A vaccine to prevent meningitis recently became available. It can be given to children as young as 2 years old. Many doctors recommend that children receive the vaccine no later than age 12 or 13, or before they begin high school.

A condition called **Reye's syndrome** can occur in young people that take aspirin when they have a viral infection. The syndrome causes swelling of the brain and may be fatal. Fortunately, Reye's syndrome is very rare. The best way to prevent it is by not taking aspirin when you have a viral infection. Products like cold medicines often contain aspirin. Therefore, it's important to read labels carefully when taking any medicines (**Figure** 20.34).

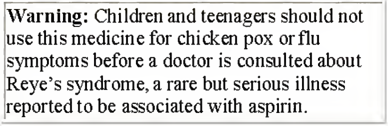
Warning: Children and teenagers should not use this medicine for chicken pox or flu symptoms before a doctor is consulted about Reye's syndrome, a rare but serious illness reported to be associated with aspirin.

Figure 20.34: Since 1988, the U.S. Food and Drug Administration has required that all aspirin and aspirin-containing products carry this warning label. (38)

Other Nervous System Diseases

Like other parts of the body, the nervous system may develop tumors. A **tumor** is a mass of cells that grow out of control. A tumor in the brain may press on normal brain tissues. This can cause headaches, difficulty speaking, or other problems, depending on where the tumor is located. Pressure from a tumor can even cause permanent brain damage. In many cases, brain tumors can be removed with surgery. In other cases, tumors can't be removed without damaging the brain even more. In those cases, other types of treatments may be needed.

Cerebral palsy is a disease caused by injury to the developing brain. The injury occurs before, during, or shortly after birth. Cerebral palsy is more common in babies that have a low weight at birth. However, the cause of the brain injury is not often known for certain. The parts of the brain that control body movements are usually affected. Symptoms range from weak muscles in mild cases, to trouble walking and talking in more severe cases. There is no known cure for cerebral palsy.

Epilepsy is a disease in which seizures occur. A **seizure** is a period of lost consciousness that may include violent muscle contractions. It is caused by abnormal electrical activity in the brain. The underlying cause of epilepsy may be an infection, brain injury, or tumor. The seizures of epilepsy can often be controlled with medicine. There is no known cure for the disease, but children with epilepsy may outgrow it by adulthood.

A headache is a very common nervous system problem. Headaches may be a symptom of serious diseases such as brain tumors or encephalitis. More commonly, they are due to muscle tension. A **tension headache** occurs when muscles in the shoulders, neck, and head become too tense. This often happens when people are "stressed out." Just trying to relax

may help relieve this type of headache (**Figure** 20.35). Mild pain relievers such as ibuprofen may also help.

Figure 20.35: Sometimes relaxation is the best "medicine" for a tension headache, and to help muscles get rid of pain. (6)

A **migraine** is a more severe type of headache. It occurs when blood vessels in the head dilate, or expand. This may be triggered by certain foods, bright lights, weather changes, or other factors. People with migraines may also have nausea or other symptoms. Fortunately, migraines can often be relieved with prescription drugs.

There are many other nervous system diseases. They include multiple sclerosis, Huntington's disease, Parkinson's disease, and Alzheimer's disease. However, these diseases rarely, if ever, occur in young people. Their causes and symptoms are listed in **Table** (20.3). The diseases have no known cure, but medicines may help control their symptoms.

Table 20.3: **Other Diseases of the Nervous System**

Disease	Cause	Symptoms
Multiple Sclerosis	The immune system attacks and damages the central nervous system so neurons cannot function normally.	Muscle weakness, difficulty moving, problems with coordination, difficulty keeping the body balanced
Huntington's Disease	An inherited defective gene codes for an abnormal protein that causes the death of neurons.	Uncontrolled jerky movements, loss of muscle control, problems with memory and learning

Table 20.3: (continued)

Disease	Cause	Symptoms
Parkinson's Disease	An abnormally low level of a neurotransmitter affects the part of the brain that controls movement.	Rigid muscles, uncontrolled shaking, slowed movements, problems with speaking
Alzheimer's Disease	Abnormal changes in the brain cause the gradual loss of most normal brain functions.	Memory loss, confusion, mood swings, gradual loss of control over mental and physical abilities

Injuries to the Central Nervous System

Injuries to the central nervous system may damage tissues of the brain or spinal cord. If an injury is mild, a person may have a full recovery. If an injury is severe, it may cause permanent disability or even death. Brain and spinal cord injuries most commonly occur because of car crashes or sports accidents. The best way to deal with such injuries is to try to prevent them.

Brain Injuries

The mildest and most common type of brain injury is a **concussion.** This is a bruise on the surface of the brain. It may cause temporary problems such as headache, drowsiness, and confusion. Most concussions in young people occur when they are playing sports, especially contact sports like football. A concussion normally heals on its own in a few days. A single concussion is unlikely to cause permanent damage. However, repeated concussions may lead to lasting problems. People that have had two or more concussions may have life-long difficulties with memory, learning, speech, or balance. You can see an animation of a how a concussion occurs by visiting http://pennhealth.com/health_info/ animation-player/concussion.html.

A person with a serious brain injury usually suffers permanent brain damage. As a result, the person may have trouble talking or controlling body movements. Symptoms depend on what part of the brain was injured. Serious brain injuries can also cause personality changes and problems with mental abilities such as memory. Medicines, counseling, and other treatments may help people with serious brain injuries recover from—or at least learn to cope with—their disabilities.

Spinal Cord Injuries

Spinal cord injuries interrupt messages between the brain and body. They may cause a person to lose the ability to feel or move parts of the body. This is called **paralysis.** Whether paralysis occurs—and what parts of the body are affected if it does—depend on the location and seriousness of the injury. In addition to car crashes and sports injuries, diving accidents are a common cause of spinal cord injuries.

Some people recover from spinal cord injuries. However, many people are paralyzed for life. Thanks to the work of Christopher Reeve (**Figure** 20.36), more research is being done on spinal cord injuries now than ever before. For example, scientists are trying to discover ways to regrow damaged spinal cord neurons.

Figure 20.36: Former *Superman* star, Christopher Reeve, was paralyzed from the neck down in a fall from a horse; the injury crushed his spinal cord so his brain could no longer communicate with his body. (35)

Dangers of Alcohol and Other Drugs

A **drug** is any chemical substance that affects the body or brain. Some drugs are medicines (**Figure** 20.37). Although these drugs are helpful when used properly, they can be misused like any other drugs. Drugs that aren't medicines include both legal and illegal drugs. Examples of legal drugs are alcohol and caffeine. Although these drugs can be used legally by adults, they can still do harm. Examples of illegal drugs include marijuana and cocaine.

Figure 20.37: Drugs that are prescribed by a doctor can be misused just like illegal drugs. (33)

Types of Psychoactive Drugs

Drugs like alcohol, marijuana, and cocaine affect the brain. Drugs that affect the brain are called **psychoactive drugs.** They influence how a person feels, thinks, or acts. You can watch animations of psychoactive drugs and the brain at `http://www.pbs.org/wnet/closetohome/science/html/animations.html`.

If you think you have never used a psychoactive drug, think again. Do you drink soft drinks, such as colas? Most of them contain caffeine, which is a psychoactive drug. Caffeine is also found in coffee and chocolate (**Figure** 20.38).

Figure 20.38: All three of these popular products contain the stimulant drug caffeine. (1)

Caffeine is an example of a class of psychoactive drugs called stimulant drugs. Other classes of psychoactive drugs are depressant drugs and hallucinogenic drugs. Drugs are classified based on how they affect the nervous system.

- A **stimulant drug** is a psychoactive drug that speeds up the nervous system. This type of drug may make people feel more alert. Stimulants also increase heart rate and blood pressure. High doses of stimulant drugs can be dangerous. They can even cause death. Other stimulant drugs include nicotine (in tobacco) and cocaine.
- A **depressant drug** is psychoactive drug that slows down the nervous system. This type of drug may make people feel calm and drowsy. It also decreases heart rate and the rate of breathing. High doses of depressant drugs can be dangerous. They may slow down the nervous system so much that heartbeat and breathing stop. Examples of depressant drugs include alcohol and morphine.
- An **hallucinogenic drug** is a psychoactive drug that can cause strange sensations, perceptions, and thoughts. Examples of hallucinogenic drugs include marijuana and LSD.

Drug Abuse

Psychoactive drugs, both legal and illegal, are often abused. **Drug abuse** is the use of a drug without the advice of a doctor or for reasons other than those for which the drug was

intended. Drug abuse may lead to **physical dependence** on the drug. This occurs when drug abusers need a drug to feel well physically. If they stop using the drug, they may experience symptoms like vomiting, diarrhea, or depression. This is called **withdrawal.** Drug abuse may also lead to **psychological dependence.** This occurs when drug abusers need a drug to feel well emotionally and mentally.

For some drug abusers, a drug takes over their life. Their thoughts and activities revolve around getting and using the drug. No matter what the consequences, they keep using the drug. Even if they want to stop using the drug, they can't. When drug abuse reaches this state, it's called **drug addiction.** Alcohol, nicotine, and cocaine are all highly addictive drugs.

People that are addicted to a drug may need to take more of the drug to feel the same effects as when they first started using the drug. This is called **tolerance.** People that develop tolerance are at risk of a **drug overdose.** A drug overdose occurs when someone takes so much of a drug that it causes serious illness or death.

Keeping the Nervous System Healthy

There are many choices you can make to keep your nervous system healthy. One obvious choice is to avoid using alcohol or other drugs. Not only will you avoid the injury that drugs themselves can cause. You will also be less likely to get involved in other risky behaviors that could harm your nervous system.

Another way to keep the nervous system healthy is to eat a variety of healthy foods. The minerals calcium and potassium and vitamins B_1 and B_{12} are important for a healthy nervous system. Some foods that are good sources for these minerals and vitamins are shown **Figure** 20.39.

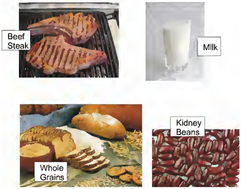

Figure 20.39: These foods are sources of nutrients needed for a healthy nervous system. (22)

Daily physical activity is also important for nervous system health. Regular exercise makes your heart more efficient at pumping blood to your brain. As a result, your brain gets more

oxygen, which it needs to function normally.

The saying "use it or lose it" applies to your brain as well as your body. This means that mental activity, not just physical activity, is important for nervous system health. Doing crossword puzzles, reading, and playing a musical instrument are just a few ways you can keep your brain active.

You can also choose to practice safe behaviors to protect your nervous system from injury. To keep your nervous system safe, choose to

- Wear safety goggles or sunglasses when needed to protect your eyes from injury.
- Wear hearing protectors such as ear plugs to protect your ears from loud sounds.
- Wear a safety helmet for activities like bike riding and skating (**Figure** 20.40).
- Wear a safety belt every time you ride in a motor vehicle.
- Avoid unnecessary risks, such as performing dangerous stunts on your bike.
- Never dive into water that is not approved for diving. If the water is too shallow, you could seriously injure your brain or spinal cord. A few minutes of fun could turn into a lifetime in a wheelchair.

Figure 20.40: Bicycle helmets help protect from head injuries; making healthy choices like this can help prevent nervous system injuries that could cause lifelong disability. (27)

Lesson Summary

- The nervous system can be affected by infections, tumors, and other diseases.

- Brain or spinal cord injuries may cause permanent disability or even death.

- The use of psychoactive drugs can lead to drug abuse or addiction.

- You can make choices that will help keep your nervous system healthy and safe.

Review Questions

1. What is encephalitis?
2. What causes muscle weakness in cerebral palsy?
3. List symptoms of a concussion.
4. Define psychoactive drug and name two examples.
5. List three choices you can make to keep your nervous system healthy.
6. Explain why young people should not take aspirin when they have the flu, which is caused by viruses.
7. Compare and contrast tension headaches and migraine headaches.
8. Explain what causes paralysis.
9. Which type of psychoactive drug is caffeine? How does caffeine affect the nervous system?
10. How is drug tolerance related to drug overdose?

Further Reading / Supplemental Links

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Vocabulary

cerebral palsy Disease caused by injury to the developing brain early in life that affects the control of body movements.

concussion Bruise on the surface of the brain; the mildest and most common type of brain injury.

depressant drug Psychoactive drug that slows down the nervous system.

drug Any chemical substance that affects the body or brain.

drug abuse Use of a drug without the advice of a doctor or for reasons other than those for which the drug was intended.

drug addiction Condition in which a drug takes over people's lives and they cannot stop using the drug even if they want to.

drug overdose Taking so much of a drug that it causes serious illness or death.

encephalitis Infection of the brain that is usually caused by viruses.

epilepsy Disease in which seizures occur.

hallucinogenic drug Psychoactive drug that can cause strange sensations, perceptions, and thoughts.

meningitis Viral or bacterial infection of the membranes that cover the brain and spinal cord.

migraine Severe type of headache that occurs when blood vessels in the head dilate.

paralysis Inability to feel or move parts of the body.

physical dependence Condition in which drug abusers need a drug to feel well physically.

psychoactive drug Drug that affects the brain and influences how a person feels, thinks, or acts.

psychological dependence Condition in which drug abusers need a drug to feel well emotionally.

Reye's Syndrome Rare, potentially fatal condition associated with aspirin use in young people with viral infections.

seizure Period of lost consciousness that may include violent muscle contractions.

stimulant drug Psychoactive drug that speeds up the nervous system.

tension headache Headache that occurs when muscles in shoulders, neck, and head become too tense.

tolerance Condition in which people need to take more of a drug to feel the same effects as when they first started using the drug.

tumor Mass of cells that grow out of control; associated with cancer.

withdrawal Symptoms like vomiting, diarrhea, or depression that can occur when people stop using a drug.

Points to Consider

- Although the nervous system controls the body, it doesn't do it alone. It gets help from another body system, called the endocrine system. This is a system of glands that secrete hormones. Hormones are chemicals released by cells that affect cells in other parts of the body.
- Think of how hormones can help control body processes?

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Chapter 21

Diseases and the Body's Defenses

21.1 Lesson 21.1: Infectious Diseases

Lesson Objectives

- List common causes of infectious diseases.
- Explain how the virus known as HIV causes AIDS.
- State how infectious diseases can be prevented.

Check Your Understanding

- What is a bacteria?
- What are the components of blood?

Introduction

Has this ever happened to you? A student sitting next to you in class has a cold. The other student is coughing and sneezing, but you feel fine. Two days later, you come down with a cold, too. Diseases like colds are contagious, or "catching." Contagious diseases are also called infectious diseases. An **infectious disease** is a disease that spreads from person to person.

Causes of Infectious Diseases

Infectious diseases are caused by pathogens. A **pathogen** is a living thing or virus that causes disease. Pathogens are commonly called "germs." They can travel from one person to

another. This is why the diseases they cause are "catching."

Types of Pathogens

Living things that cause human diseases include bacteria, fungi, and protozoa. Most infectious diseases caused by these organisms can be cured with medicines. For example, medicines called antibiotics can cure most diseases caused by bacteria.

Bacteria are one-celled living things without a nucleus. Although most bacteria are harmless, some cause diseases. Worldwide, the most common disease caused by bacteria is tuberculosis (TB). TB is a serious disease of the lungs. Another common disease caused by bacteria is strep throat. You may have had strep throat yourself. Bacteria that cause strep throat are shown in **Figure** 21.1. Some types of pneumonia and many cases of food borne illnesses are also caused by bacteria.

Figure 21.1: The structures that look like strings of beads are bacteria. They belong to the genus *Streptococcus*. Bacteria of this genus cause diseases such as strep throat and pneumonia. They are shown here 900 times bigger than their actual size. (4)

Fungi are simple organisms that consist of one or more cells. They include mushrooms and yeasts. Human diseases caused by fungi include ringworm and athlete's foot. Both are skin diseases that are not usually serious. What a ringworm infection looks like is shown in **Figure** 21.2. A more serious fungus disease is histoplasmosis. It is a lung infection.

Protozoa are one-celled eukaryotes (with a nucleus). They cause diseases such as malaria. Malaria is a serious disease that is common in warm climates; the protozoa is transferred to people by a mosquito. More than a million people die of malaria each year. Other protozoa cause diarrhea. An example is *Giardia lamblia*, which is shown in **Figure** 21.3.

Figure 21.2: Ringworm isn't a worm at all. It's a disease caused by a fungus. The fungus causes a ring-shaped rash on the skin, like the one shown here. (14)

Figure 21.3: This picture shows a one-celled organism called *Giardia lamblia*. It is a protozoan that causes diarrhea. (16)

Viruses are nonliving particles that take over living cells in order to multiply. Viruses cause many common diseases. For example, viruses cause colds and flu. Cold sores are caused by the virus *Herpes simplex*. This virus is shown in **Figure** 21.4. Antibiotics do not affect viruses. However, medicines called antiviral drugs can treat many diseases caused by viruses.

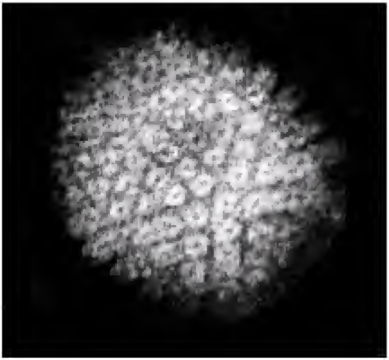

Figure 21.4: The *Herpes simplex* virus, which is shown here, causes cold sores on the lips. Viruses are extremely small particles. This one is greatly magnified. (1)

How Pathogens Spread

Different pathogens spread in different ways. Some pathogens spread through food. They cause food borne illnesses. These illnesses were discussed in the *Food and Digestive System* chapter. Some pathogens spread through water. *Giardia lamblia* is one example. Water can be boiled or purified in other ways to kill *Giardia* and most other pathogens. Several pathogens spread through sexual contact. HIV is one example. It is a virus you will read about below. Other pathogens that spread through sexual contact are discussed in the Reproductive Systems and Life Stages chapter.

Many pathogens that cause respiratory diseases spread by droplets in the air. Droplets are released when a person sneezes or coughs. Thousands of tiny droplets are released when a person sneezes is shown in **Figure** 21.5. Each droplet can contain thousands of pathogens. Examples of pathogens spread in this way are the viruses that cause colds and flu. You may get sick if you breathe in the pathogens.

Figure 21.5: As this picture shows, thousands of tiny droplets are released into the air when a person sneezes. Each droplet may carry thousands of pathogens. You can't normally see the droplets from a sneeze because they are so small. However, you can breathe them in, along with any pathogens they carry. This is how many diseases of the respiratory system are spread. (17)

Other pathogens spread when they get on objects or surfaces. A fungus may spread in this way. For example, you can pick up the fungus that causes athlete's foot by wearing shoes an infected person has worn. You can also pick up this fungus from the floor of a public shower. After acne, athlete's foot is the most common skin disease in the United States. Therefore, the chance of coming in contact with the fungus in one of these ways is fairly high. Bacteria that cause the skin disease impetigo can spread when people share towels or clothes. The bacteria can also spread through direct skin contact in sports like wrestling.

Still other pathogens are spread by vectors. A **vector** is an organism that carries pathogens from one person or animal to another. Most vectors are insects, such as ticks and mosquitoes. When an insect bites an infected person or animal, it picks up the pathogen. Then it transfers the pathogen to the next person or animal it bites. Ticks carry the bacteria that cause Lyme disease. Mosquitoes, like the one in **Figure** 21.6, carry West Nile virus. Both pathogens cause fever, headache, and tiredness. If the diseases are not treated, more serious symptoms may develop.

The first case of West Nile virus in North America occurred in 1999. Within just a few years, the virus had spread throughout most of the United States. Birds as well as humans can be infected with the virus. Birds often fly long distances. This is one reason why West Nile virus spread so quickly.

Figure 21.6: Some diseases are spread by insects. The type of mosquito shown here can spread West Nile virus. The virus doesn't make the mosquito sick. The mosquito just carries the virus from one person or animal to another. (5)

HIV Infection and AIDS

HIV, or human immunodeficiency virus, causes AIDS. **AIDS** stands for acquired immune deficiency syndrome. It is a fatal condition with no known cure. AIDS usually develops 10 to 15 years after a person is first infected with HIV.

How HIV Spreads

HIV spreads through direct contact of mucous membranes or the bloodstream with an infected person's body fluids. Body fluids that may contain HIV include blood, semen, vaginal fluid, and breast milk. The virus can spread through sexual contact or shared drug needles. It can also spread from an infected mother to her baby during childbirth or breastfeeding.

Some people think they can become infected with HIV by donating blood or receiving donated blood. This is not true. The needles used to draw blood for donations are always new. Therefore, they cannot spread the virus. Donated blood is also tested to make sure it is free of HIV.

HIV and the Immune System

How does an HIV infection develop into AIDS? HIV destroys white blood cells called helper T cells. The cells are produced by the immune system. This is the body system that fights infections and other diseases. You will read more about the immune system in Lesson 4.

HIV invades helper T cells and uses them to reproduce. This is shown in **Figure** 21.7. Then the virus kills the helper T cells. As the number of viruses in the blood rises, the number of helper T cells falls. Without helper T cells, the immune system is unable to protect the body. As a result, the infected person cannot fight infections and other diseases.

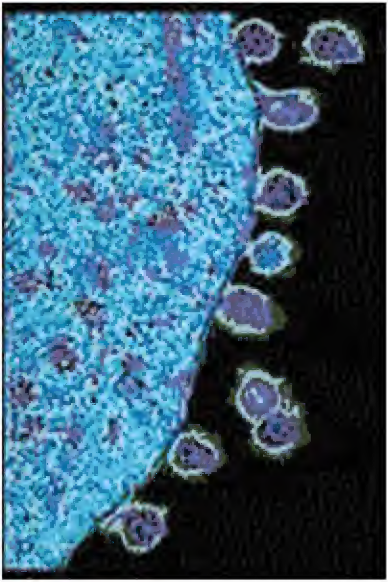

Figure 21.7: In this picture, the large structure on the left is a helper T cell. It is infected with HIV. The many small circles on the right are new HIV viruses being shed by the T cell. (24)

Medications can slow down the increase of viruses in the blood. However, the medications cannot rid the body of all the viruses. At present, there is no cure for HIV infection.

AIDS

AIDS is not really a single disease. It is a set of symptoms and other diseases. It results from years of damage to the immune system by HIV. AIDS occurs when helper T cells fall to a very low level and the person develops infections or cancers that people with a healthy immune system can easily resist. These diseases are usually the cause of death of people with AIDS.

The first known cases of AIDS occurred in 1981. Since then, AIDS has led to the deaths of more than 25 million people worldwide. Many of them were children. The greatest number of deaths occurred in Africa. This is probably where HIV first arose. It is also where medications to control HIV are least available. There are currently more people infected with HIV in Africa than any other part of the world.

Preventing Infectious Diseases

What can you do to avoid infectious diseases? Eating right and getting plenty of sleep are a good start. These habits will help keep your immune system healthy. With a healthy immune system, you will be able to fight off many pathogens.

You can also take steps to avoid pathogens in the first place. The single most important way to avoid pathogens is to wash your hands often. You should wash your hands after using the bathroom or handling raw meat or fish. You should also wash your hands before eating or preparing food. In addition, you should wash your hands after being around sick people. The correct way to wash your hands is demonstrated in **Figure** 21.8. If soap and water aren't available, use a hand sanitizer. A hand sanitizer that contains at least 60 percent alcohol will kill most germs on your hands.

The best way to prevent diseases spread by vectors is to avoid contact with the vectors. For example, you can wear long sleeves and long pants to avoid tick and mosquito bites. Using insect repellent can also reduce your risk of insect bites.

Many infectious diseases can be prevented with vaccinations. You will read more about vaccinations in Lesson 4. Vaccinations can help prevent measles, mumps, chicken pox, and several other diseases.

If you do develop an infectious disease, try to avoid infecting others. Stay home from school until you are well. Also, take steps to keep your germs to yourself. Cover your mouth and nose with a tissue when you sneeze or cough, and wash your hands often to avoid spreading pathogens to other people.

Figure 21.8: This picture shows the proper way to wash your hands. Frequent hand washing helps prevent the spread of pathogens. (22)

Lesson Summary

- Infectious diseases are caused by living things or viruses that can travel from one person to another.
- HIV causes AIDS by destroying disease-fighting cells produced by the immune system.
- A healthy lifestyle and frequent hand washing can help reduce your risk of infectious diseases.

Review Questions

1. Name two examples of infectious diseases.
2. What is a pathogen?
3. List three ways that pathogens can spread.
4. What is HIV?
5. What is the single most important way to avoid pathogens?
6. Why do antibiotics not cure the common cold?
7. Explain why covering your mouth when you cough helps prevent the spread of germs.
8. What role do vectors play in the spread of infectious diseases?
9. How does an HIV infection develop into AIDS?
10. Why might using insect repellent reduce your risk of Lyme disease?

Further Reading / Supplemental Links

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Vocabulary

AIDS Acquired immune deficiency syndrome, which is a fatal condition caused by HIV.

HIV The human immunodeficiency virus, which causes AIDS.

infectious disease A disease that spreads from person to person.

pathogen A living organism or virus that causes disease.

vector An organism that carries pathogens from one person or animal to another.

Points to Consider

- What do you think causes allergies?
- Do you know of other diseases that are not caused by pathogens?
- Do you think these diseases are contagious?

21.2 Lesson 21.2: Noninfectious Diseases

Lesson Objectives

- List causes of noninfectious diseases.
- Describe causes and treatments of cancer.
- Explain why diabetes occurs.
- Describe autoimmune diseases and allergies.
- State how noninfectious diseases can be prevented.

Check Your Understanding

- What is an infectious disease?
- Discuss the stages of the cell cycle.

Introduction

Not all diseases spread from person to person. A disease that does not spread from person to person is called a **noninfectious disease**. Examples are cancer and diabetes. These diseases may or may not be caused by pathogens.

Causes of Noninfectious Diseases

Most noninfectious diseases have more than one cause. The causes may include genes and an unhealthy lifestyle. Genes may increase the chances that people will have certain diseases. However, other factors may determine whether the diseases actually develop. For example, what people eat or whether they smoke may also play a role.

Several noninfectious diseases are discussed in other chapters. For example, heart disease is discussed in Cardiovascular System chapter. In this lesson, the focus is on cancer, diabetes, and diseases of the immune system.

Cancer

Cancer is a disease in which abnormal cells divide out of control. Normally, the body has safeguards that prevent abnormal cells from dividing. In cancer, these safeguards fail.

What Causes Cancer?

Cancer is usually caused by mutations. From the *Cell Division, Reproduction, and DNA* chapter, you know that mutations are random errors in genes. Mutations that lead to cancer (usually multiple mutations in the same cell) usually occur in genes that control the cell cycle. Due to the mutations, abnormal cells divide uncontrollably. This often leads to a tumor. A **tumor** is a mass of abnormal tissue. As a tumor grows, it may harm normal tissues around it.

Anything that can cause cancer is called a **carcinogen**. Carcinogens may be pathogens, chemicals, or radiation. Figure 1 gives examples of carcinogens of each type.

Causes of Cancer

Pathogens Pathogens that cause cancer include the human papilloma virus (HPV) and the hepatitis B virus. HPV is spread through sexual contact. It can cause cancer of the reproductive system in females. The hepatitis B virus is spread through sexual contact or contact with blood containing the virus. It can cause cancer of the liver (**Figures** 21.9 and 21.10).

Chemicals Many different chemical substances cause cancer. Dozens of chemicals in tobacco smoke, including nicotine, have been shown to cause cancer. In fact, tobacco smoke is one of the main sources of chemical carcinogens. Smoking tobacco increases the risk of cancer of the lung, mouth, throat, and bladder. Using smokeless tobacco can also cause cancer.

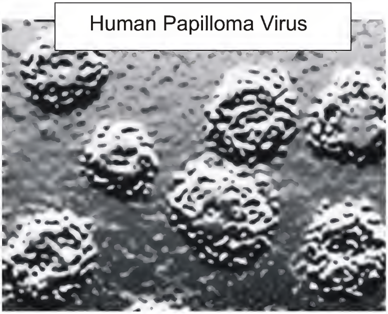

Figure 21.9: The mutations that cause cancer may occur when people are exposed to pathogens, chemicals, or radiation. Some common causes of cancer are shown here. (23)

Figure 21.10: The mutations that cause cancer may occur when people are exposed to pathogens, chemicals, or radiation. Some common causes of cancer are shown here. (6)

Radiation Forms of radiation that cause cancer include ultraviolet (UV) radiation and radon. UV radiation is part of sunlight. It is the leading cause of skin cancer. Radon is a natural radioactive gas that seeps into buildings from the ground. It can cause lung cancer (**Figure** 21.11).

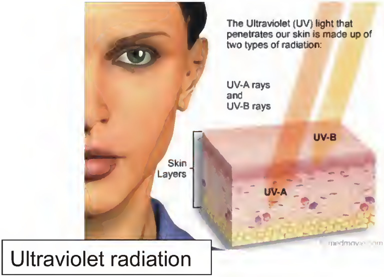

Figure 21.11: The mutations that cause cancer may occur when people are exposed to pathogens, chemicals, or radiation. Some common causes of cancer are shown here. (9)

Sometimes cancer cells break away from a tumor. If they enter the bloodstream, they are carried throughout the body. Then, the cells may start growing in other tissues. This is usually how cancer spreads from one part of the body to another. Once this happens, cancer is very hard to control.

Common Types of Cancer

Cancer occurs mainly in adults, especially in adults over age 50, as more mutations accumulate in cells over time. The most common type of cancer in adult males is cancer of the prostate gland. The prostate gland is part of the male reproductive system. Prostate cancer makes up about one third of all cancers in men. The most common type of cancer in adult females is breast cancer. It makes up about one third of all cancers in women. In both men and women, lung cancer is the second most common type of cancer. Most cases of lung cancer occur in smokers.

Cancer can also occur in children. However, childhood cancer is rare. Leukemia is the main type of cancer in children. It makes up about one third of all childhood cancers. It occurs when the body makes abnormal white blood cells.

Treating Cancer

If leukemia is treated early, it usually can be cured. In fact, many cancers can be cured if treated early. Treatment of cancer often involves removing a tumor with surgery. This may be followed by other types of treatments. These may include drugs and radiation, which kill cancer cells.

The sooner cancer is treated, the greater the chances of a cure. This is why it is important to know the warning signs of cancer. Having warning signs does not mean that you have cancer. However, you should see a doctor to be sure.

Everyone should know the warning signs of cancer. Detecting and treating cancer early can often lead to a cure.

Warning Signs of Cancer

- Change in bowel or bladder habits
- Sore that doesn't heal
- Unusual bleeding or discharge
- Lump in the breast or elsewhere
- Chronic indigestion
- Difficulty swallowing
- Obvious changes in a wart or mole
- Persistent cough or hoarseness

(*Source*: http://www.uihealthcare.com/topics/cancer/canc4280.html, *Courtesy:* University of Iowa Hospitals and Clinics)

Diabetes

Another noninfectious disease is diabetes. **Diabetes** is a disease in which the pancreas cannot make enough insulin. From the Controlling the Body chapter, you know that insulin is a hormone that helps cells take up sugar from the blood. Without enough insulin, the blood contains too much sugar. This can damage blood vessels and other cells throughout the body. The kidneys work hard to filter out and excrete some of the excess sugar. This leads to frequent urination and excessive thirst.

Doctor Rosalyn Yalow is an American scientist that played a major role in our knowledge of diabetes. She helped discover a way to measure tiny amounts of insulin in the blood. She won a Nobel Prize for her discovery in 1977.

There are two main type of diabetes: type 1 diabetes and type 2 diabetes. Type 1 diabetes makes up about 5 to 10 percent of all cases of diabetes in the United States. Type 2 diabetes

accounts for most of the other cases. Both types of diabetes are more likely in people that have certain genes. Therefore, having a family member with diabetes increases the risk of developing the disease. Either type of diabetes can increase the chances of having other health problems, as well. For example, people with diabetes are more likely to develop heart disease and kidney disease. Type 1 and type 2 diabetes are similar in these ways. However, the two types of diabetes have different causes.

Type 1 Diabetes

Type 1 diabetes occurs when the immune system attacks normal cells of the pancreas. As a result, the pancreas can no longer produce insulin. Something in the environment triggers the immune system to attack the pancreas. Scientists think that the trigger may be a virus. Type 1 diabetes usually develops in childhood or adolescence.

People with type 1 diabetes must frequently check the sugar in their blood. They use a meter like the one shown in **Figure** 21.12. Whenever their blood sugar starts to get too high, they need a shot of insulin. The insulin brings their blood sugar back to normal. There is no cure for type 1 diabetes. Therefore, insulin shots must be continued for life. Most people with this type of diabetes learn how to give themselves insulin shots.

Type 2 Diabetes

Type 2 diabetes occurs when body cells no longer respond to insulin. The pancreas may still produce insulin, but the cells of the body cannot use it. Being overweight and having high blood pressure increase the chances of developing this type of diabetes. Type 2 diabetes usually develops in adulthood. However, it is becoming more common in teens and children. This is because more young people are overweight now than ever before.

Some cases of type 2 diabetes can be cured with weight loss. However, most people with the disease need to take medicine to control their blood sugar. Regular exercise and balanced eating also help. Like people with type 1 diabetes, people with type 2 diabetes must frequently check their blood sugar.

Diseases of the Immune System

The immune system usually protects you from pathogens and other causes of disease. In Lesson 4, you will read more about how the immune system works. When the immune system is working properly, it keeps you from getting sick. However, the immune system is like any other system of the body. It can break down or develop diseases. In the last lesson you read about AIDS. AIDS is an infectious disease of the immune system caused by a virus. Some diseases of the immune system are noninfectious. They include autoimmune diseases and allergies.

Figure 21.12: This is one type of meter used by people with diabetes to measure their blood sugar. Modern meters like this one need only a drop of blood and take less than a minute to use. (25)

Autoimmune Diseases

An **autoimmune disease** occurs when the immune system attacks the body's own cells. One example is type 1 diabetes. In this disease, the immune system attacks cells of the pancreas. Other examples are multiple sclerosis and rheumatoid arthritis. In multiple sclerosis, the immune system attacks nerve cells. This causes weakness and pain. In rheumatoid arthritis, the immune system attacks the cells of joints. This causes joint damage and pain. These diseases cannot be cured. However, they can be helped with medicines that weaken the immune system's attack on normal cells.

Allergies

An **allergy** occurs when the immune system attacks a harmless foreign substance. A substance that triggers an allergy is called an **allergen**. It is the response of the immune system, not the allergen, which causes the symptoms of an allergy.

Did you ever hear of hay fever? It's not really a fever at all. It's an allergy to plant pollens. People with this type of allergy have symptoms such as watery eyes, sneezing, and a runny nose. A common cause of hay fever is the pollen of ragweed. A ragweed plant is shown in **Figure** 21.13.

Many people are allergic to poison ivy. A poison ivy plant is shown in **Figure** 21.14. Skin contact with poison ivy leads to an itchy rash in people that are allergic to the plant.

As you have read, some people are allergic to certain foods. Nuts and shellfish are common causes of food allergies. Other common causes of allergies include:

- drugs such as penicillin
- mold
- dust
- dog and cat dander (dead skin cells)
- stings of wasps and bees

To learn more about allergies and their causes, go to http://aafa_al.healthology.com/allergies/focusarea.htm. You can watch a video about allergies at this Web site.

Most allergies can be treated with medicines. Medicines used to treat allergies include antihistamines and steroids. These medicines help control the immune system's response. Sometimes, allergies cause severe symptoms. For example, they may cause the throat to swell so it is hard to breathe. Severe allergies may be life threatening. They require emergency medical care.

Figure 21.13: Ragweed is a common roadside weed found throughout the United States. Many people are allergic to its pollen. (28)

Figure 21.14: Poison ivy plants are wild vines with leaves in groups of three. They grow in wooded areas in most of the United States. Contact with poison ivy may cause a rash in a person allergic to the plant. (21)

Preventing Noninfectious Diseases

Most allergies can be prevented by avoiding the substances that cause them. For example, you can avoid pollens by staying indoors as much as possible. You can learn to recognize plants like poison ivy and not touch them. A good way to remember how to avoid poison ivy is "Leaves of three, let it be." Some people receive allergy shots to help prevent allergic reactions. The shots contain tiny amounts of allergens. After many months or years of shots, the immune system gets used to the allergens and no longer responds to them.

Type 1 diabetes and other autoimmune diseases cannot be prevented. However, choosing a healthy lifestyle can help prevent type 2 diabetes. Getting plenty of exercise, avoiding high-fat foods, and staying at a healthy weight can reduce the risk of developing this type of diabetes. This is especially important for people that have family members with the disease.

Making these healthy lifestyle choices can also help prevent some types of cancer. In addition, you can reduce the risk of cancer by avoiding carcinogens. For example, you can reduce your risk of lung cancer by not smoking. You can reduce your risk of skin cancer by using sunscreen. How to choose a sunscreen that offers the most protection is explained in **Figure** 21.15.

Some people think that tanning beds are a safe way to get a tan. This is a myth. Tanning beds expose the skin to UV radiation. Any exposure to UV radiation increases in the risk of skin cancer. It doesn't matter whether the radiation comes from tanning lamps

Figure 21.15: When you choose a sunscreen, select one with an SPF of 30 or higher. Also, choose a sunscreen that protects against both UVB and UVA radiation. (12)

or the sun.

Lesson Summary

- Causes of noninfectious diseases may include genes and an unhealthy lifestyle.
- Cancer is caused by mutations and treated with surgery, drugs, and radiation.
- Diabetes is a disease in which the pancreas cannot make enough insulin or use the insulin properly.
- Autoimmune diseases occur when the immune system attacks normal body cells.
- Allergies occur when the immune system attacks harmless foreign substances.
- A healthy lifestyle can help reduce your risk of developing many noninfectious diseases.

Review Questions

1. What is a noninfectious disease?
2. List three carcinogens.
3. What other health problems are more likely in people with diabetes?
4. What causes rheumatoid arthritis?
5. How can you reduce your risk of developing skin cancer?
6. Explain how mutations can lead to cancer.
7. Why are frequent urination and excessive thirst symptoms of diabetes?
8. Compare and contrast type 1 and type 2 diabetes.
9. Some allergies occur during certain seasons, while others occur year-round. Give examples of allergens that you would expect to cause each type of allergy.
10. Why is maintaining a healthy weight especially important for people that have family members with type 2 diabetes?

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Vocabulary

allergen A substance that triggers an allergy.

allergy A condition that occurs when the immune system attacks a harmless foreign substance.

autoimmune disease A disease that occurs when the immune system attacks the body's own cells.

cancer A disease in which abnormal cells divide out of control.

carcinogen Anything that can cause cancer.

diabetes A disease in which the pancreas cannot make enough insulin.

noninfectious disease Disease that does not spread from person to person.

tumor A mass of abnormal tissue.

type 1 diabetes The type of diabetes that occurs when the immune system attacks normal cells of the pancreas.

type 2 diabetes Type of diabetes that occurs when body cells no longer respond to insulin.

Points to Consider

- How do you think the body fights diseases like colds?
- How do you think it protects you from pathogens and other causes of disease?

21.3 Lesson 21.3: First Two Lines of Defense

Lesson Objectives

- Describe your body's first line of defense against pathogens.
- Explain how inflammation helps protect you from pathogens.

Check Your Understanding

- What are some of the functions of your skin?
- What is a pathogen? Give some examples.

Introduction

Your body has many ways to protect you from pathogens. Your body's defenses are like a castle of old. The outside of a castle was protected by a moat and high walls. Inside the castle, soldiers were ready to fight off any enemies that made it across the moat and over the walls. Like a castle, your body has a series of defenses. Only pathogens that get through all the defenses can harm you.

First Line of Defense

Your body's first line of defense is like a castle's moat and walls. It keeps most pathogens out of your body. The first line of defense includes different types of barriers.

Skin and Mucous Membranes

The skin is a very important barrier to pathogens. The skin is the body's largest organ. In adults, it covers an area of 1.5 to 2 square meters (about 16 to 22 square feet)! The skin is also the body's single most important defense. It forms a physical barrier between the body and the outside world. As shown in **Figure** 21.16, the skin has several layers. The outer layer is tough and waterproof. It is very difficult for pathogens to get through this layer of skin.

The mouth and nose are not lined with skin. Instead, they are lined with mucous membranes. Other organs that are exposed to the outside world, including the lungs and stomach, are also lined with mucous membranes. Mucous membranes are not tough like skin. However, they have other defenses.

One defense of mucous membranes is the mucus they secrete. **Mucus** is a sticky, moist substance that coats mucous membranes. Most pathogens get stuck in the mucus before they can do harm to the body. Many mucous membranes also have **cilia**. Cilia in the lungs are shown in **Figure** 21.17. Cilia are like tiny fingers. They move in waves and sweep mucus and trapped pathogens toward body openings. When you clear your throat or blow your nose, you rid your body of the mucus and pathogens.

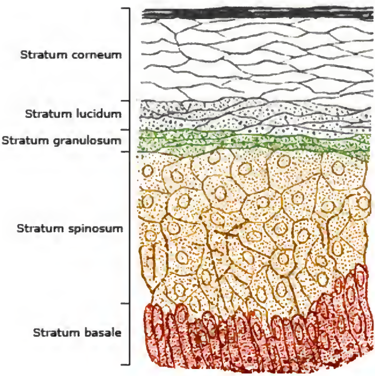

Figure 21.16: This drawing shows that the skin has many layers. The outer layer is so tough that it keeps out most pathogens. (8)

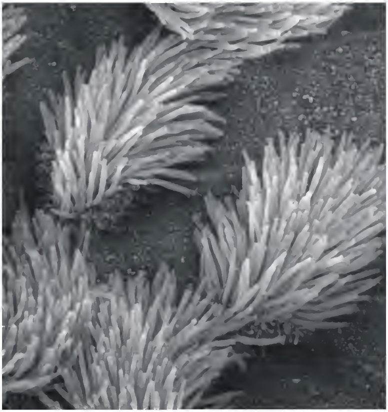

Figure 21.17: This is what the cilia lining the lungs look like when they are magnified. Their movements constantly sweep mucus and pathogens out of the lungs. Do they remind you of brushes? (15)

Chemicals

Most body secretions contain chemicals that kill pathogens. For example, mucus, sweat, tears, and saliva contain enzymes that kill pathogens. The enzymes are called lysozymes. They break down the cell walls of bacteria. The stomach secretes a very strong acid, called hydrochloric acid. This acid kills most pathogens that enter the stomach in food or water. Urine is also acidic, so few pathogens can grow in it.

Helpful Bacteria

You are not aware of them, but your skin is covered by millions (or more!) of bacteria. Millions more live inside your body. From the Food and Digestive System chapter, you know that many bacteria live inside your large intestine. Most of these bacteria help defend your body from pathogens. How do they do it? They compete with harmful bacteria for food and space. This prevents the harmful bacteria from multiplying and making you sick.

Second Line of Defense

The little girl in **Figure** 21.18 has a scraped knee. A scrape is a break in the skin that may let pathogens enter the body. If bacteria enter through the scrape, they could cause an infection. These bacteria would then face the body's second line of defense.

Inflammation

If bacteria enter the skin through a scrape, the area may become red, warm, and painful. These are signs of inflammation. **Inflammation** is one way the body reacts to infections or injuries. Inflammation is triggered by chemicals that are released when skin or other tissues are damaged. The chemicals cause nearby blood vessels to dilate, or expand. This increases blood flow to the damaged area. The chemicals also attract white blood cells to the wound and cause them to leak out of blood vessels into the damaged tissue. You can watch a video animation of this process at `http://biology-animations.blogspot.com/search/label/inflammatory%20response%20animation`.

White Blood Cells

After white blood cells leave a blood vessel at the site of inflammation, they start "eating" pathogens. From the Cardiovascular System chapter, you know that white blood cells are one type of cells that make up the blood. The main role of white blood cells is to fight pathogens in the body. There are actually several different kinds of white blood cells. Some

Figure 21.18: This little girl just got her first scraped knee. It doesn't seem to hurt, but the break in her skin could let pathogens enter her body. That's why scrapes should be kept clean and protected until they heal. (10)

white blood cells are very specialized. They attack only certain pathogens. You will read about these white blood cells in Lesson 4.

Other white blood cells attack any pathogens they find. These white blood cells travel to sites of inflammation. They are called **phagocytes**, which means "eating cells." In addition to pathogens, phagocytes "eat" dead cells and other debris. They engulf the pathogens or debris and destroy them. This process is called **phagocytosis**. How phagocytosis occurs is shown in **Figure** 21.19. You can watch a video of an actual phagocyte gobbling up and destroying a pathogen at `http://sciencevideos.wordpress.com/category/phagocytosis/`.

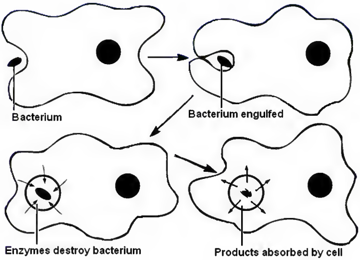

Figure 21.19: These drawings show phagocytosis. In this process, a phagocyte engulfs and breaks down a pathogen. (2)

White blood cells also produce chemicals that cause a fever. A **fever** is a higher-than-normal body temperature. Normal human body temperature is 98.6° F (37° C). Most bacteria and viruses that infect people multiply fastest at this temperature. When the temperature is higher, the pathogens cannot multiply as fast. A fever also triggers the immune system to make more white blood cells. In these ways, a fever helps the body fight infection.

Lesson Summary

- Your body's first line of defense includes the skin and other barriers that keep pathogens out of your body.
- If pathogens enter your body, inflammation occurs, and phagocytes come to the body's defense.

Review Questions

1. How does your skin protect you from pathogens?
2. What is mucus?
3. Define inflammation.
4. What are phagocytes?
5. What is a fever?
6. Explain how cilia help rid your body of pathogens.
7. How do helpful bacteria defend your body?
8. How does inflammation help fight pathogens?
9. Why is phagocytosis called a *general* body defense?
10. A fever is a sign of infection. Why might it be considered a good sign?

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Vocabulary

cilia Finger-like projects from the cells of the mucous membranes.

fever Higher than normal body temperature.

inflammation Reaction causing redness, warmth, and pain that occurs at the site of an infection or injury.

mucus Sticky, moist substance that coats mucous membranes.

phagocytes A type of white blood cells that travel to sites of inflammation and destroy pathogens and debris.

phagocytosis The process in which phagocytes engulf and destroy pathogens or debris.

Points to Consider

- How do you think pathogens can be recognized?
- Why do you think the body needs specific defenses as well as general ones?

21.4 Lesson 21.4: Immune System Defenses

Lesson Objectives

- Describe the immune system.
- Explain how lymphocytes respond to pathogens.
- Define immunity and vaccination.

Check Your Understanding

- What are the first two lines of defense?
- Give examples of pathogens.

Introduction

If pathogens manage to get through the body's first two lines of defense, a third line of defense takes over. This third line of defense involves the immune system. It is called an **immune response**. The immune system has a special response for each type of pathogen.

What Is the Immune System?

The **immune system** is also called the lymphatic system. It is named for **lymphocytes**, which are the type of white blood cells involved in an immune response. The parts of the immune system are shown in **Figure** 21.20. They include several lymph organs, lymph vessels, lymph, and lymph nodes (**Figure** 21.21).

Lymph Organs

The lymph organs are the red bone marrow, thymus gland, spleen, and tonsils. Each organ has a different function in the immune system. They are described in **Figure** 21.24.

Organs of the Immune System

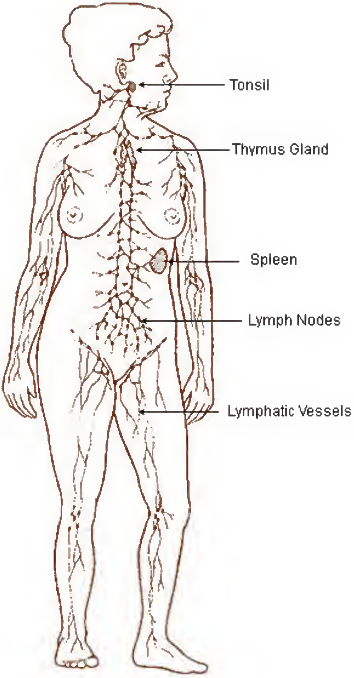

Figure 21.20: This diagram shows the parts of the immune system. The immune system includes several organs and a system of vessels that carry lymph. Lymph nodes are located along the lymph vessels. (7)

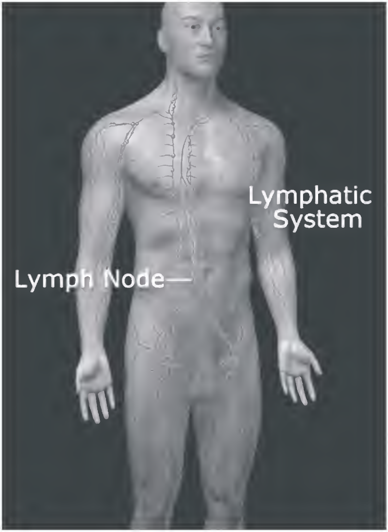

Figure 21.21: (20)

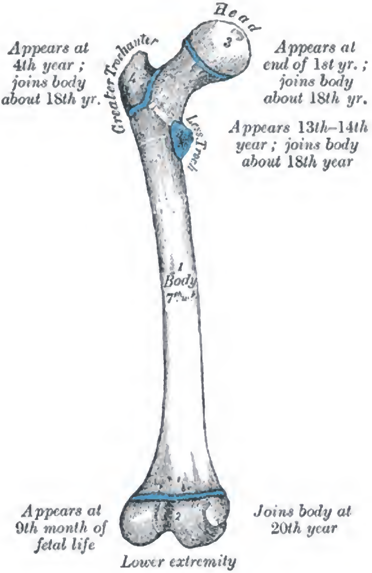

Figure 21.22: (13)

Red Bone Marrow Red bone marrow is found inside many bones, including the femur shown here. Red bone marrow produces lymphocytes.

Thymus Gland The thymus gland is in the chest behind the breast bone. It stores lymphocytes while they mature (**Figure** 21.23).

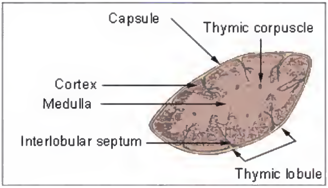

Figure 21.23: (11)

Spleen The spleen is in the abdomen below the lungs. Its job is to filter the blood. Any pathogens that are filtered out of the blood are destroyed by lymphocytes in the spleen (**Figure** 21.24).

Tonsils The tonsils are in the throat. They trap pathogens that enter the body through the mouth or nose. Lymphocytes in the tonsils destroy the trapped pathogens (**Figure** 21.25).

Lymph and Lymph Vessels

Lymph vessels make up a circulatory system that is similar to the cardiovascular system, which you read about in the Cardiovascular System chapter. Lymph vessels are like blood vessels, except they circulate lymph instead of blood. **Lymph** is a yellowish fluid that leaks out of tiny blood vessels into spaces between cells in tissues. At sites of inflammation, there is usually more lymph in tissues. This lymph may contain many pathogens.

The lymph that collects in tissues gradually passes into tiny lymph vessels. It then travels from smaller to larger lymph vessels. Lymph is not pumped through lymph vessels like blood is pumped through blood vessels by the heart. Instead, muscles surrounding the lymph vessels contract and squeeze the lymph through the vessels. The lymph vessels themselves

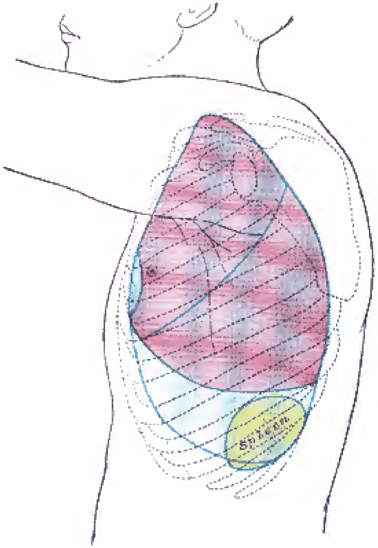

Figure 21.24: (19)

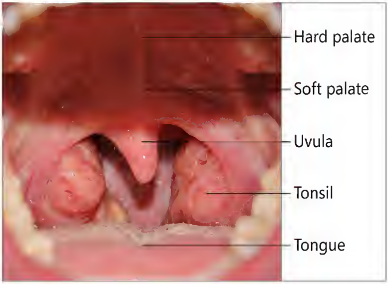

Figure 21.25: (18)

also contract to help move the lymph along. The lymph finally reaches the main lymph vessels in the chest. Here, the lymph drains into two large veins. This is how the lymph returns to the bloodstream.

Before lymph reaches the bloodstream, pathogens are removed from it at lymph nodes. **Lymph nodes** are small, oval structures located along the lymph vessels. They act like filters. Any pathogens filtered out of the lymph at lymph nodes are destroyed by lymphocytes in the nodes.

Lymphocytes

Lymphocytes are the key cells of an immune response. A photograph of a lymphocyte is shown in **Figure** 21.26. The lymphocyte shown in the figure is greatly magnified. There are trillions of lymphocytes in the human body. They make up about one quarter of all white blood cells. Usually, fewer than half of the body's lymphocytes are in the blood. The rest are in the lymph, lymph nodes, and lymph organs.

There are two main types of lymphocytes: B cells and T cells. Both types of lymphocytes are produced in the red bone marrow. They are named for the sites where they mature. The *B* in B cells stands for "bone." B cells mature in red bone marrow. The *T* in T cells stands for "thymus." T cells mature in the thymus gland. B and T cells must be "switched on" in order to fight a specific pathogen. Once this happens, they multiply and produce an army of cells ready to fight that particular pathogen.

How can B and T cells recognize specific pathogens? Pathogens have proteins that are foreign

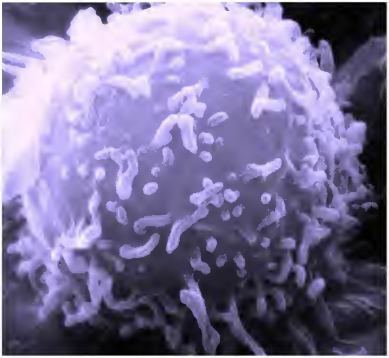

Figure 21.26: This image of a lymphocyte was made with an electron microscope. The lymphocyte is shown 10,000 times its actual size. (26)

to the body. These proteins are called antigens. An **antigen** is any protein that triggers an immune response because it is unlike any protein that the body makes. Antigens are found on bacteria, viruses, and other pathogens. They are also found on other foreign cells that enter the body and on cancer cells.

Immune Responses

There are two different types of immune responses. One type involves B cells. The other type involves T cells. You can watch a video of both types of immune responses at http://www.dnatube.com/view_video2.php?viewkey=5ff68e3e25b9114205d4.

B Cell Response

B cells respond to pathogens and other foreign cells in the blood and lymph. Most B cells fight infections by producing antibodies. An **antibody** is a large, Y-shaped protein that binds with an antigen. Each antibody can bind with just one specific type of antigen. A diagram of an antibody binding with an antigen is shown in **Figure** 21.27. They fit together like a lock and key. Antibodies travel through the blood and lymph, binding with any matching antigens they run into. Once an antigen and antibody bind together, they are destroyed by a phagocyte.

T Cell Response

There are different types of T cells, including killer T cells and helper T cells. Killer T cells destroy infected, damaged, or cancerous body cells. How a killer T cell destroys an infected cell is illustrated in **Figure** 21.28. When the killer T cell comes into contact with the infected cell, it releases poisons. The poisons make tiny holes in the cell membrane of the infected cell. This causes the cell to burst open. Both the infected cell and the viruses inside it are destroyed.

Helper T cells do not destroy infected or damaged body cells. However, they are still necessary for an immune response. They help by secreting chemicals that control other lymphocytes. The chemicals secreted by helper T cells "switch on" both B cells and killer T cells so they can recognize and fight specific pathogens.

Immunity and Vaccination

Most B and T cells die after an infection has been brought under control. However, some of them survive for many years. They may even survive for a person's lifetime. These long-lasting B and T cells are called memory cells. They allow the immune system to "remember" the pathogen after the infection is over. If the pathogen tries to invade the body again, the

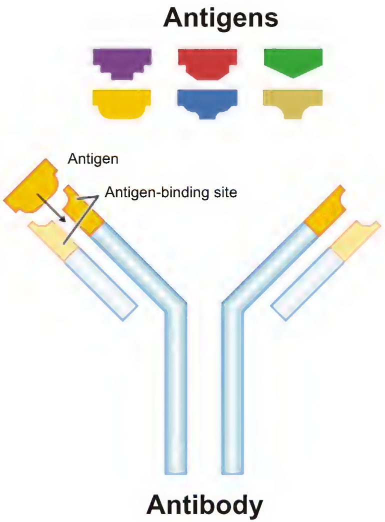

Figure 21.27: This diagram shows how an antibody binds with an antigen. The antibody was produced by a B cell. It binds with just one type of antigen. Antibodies produced by different B cells bind with other types of antigens. (3)

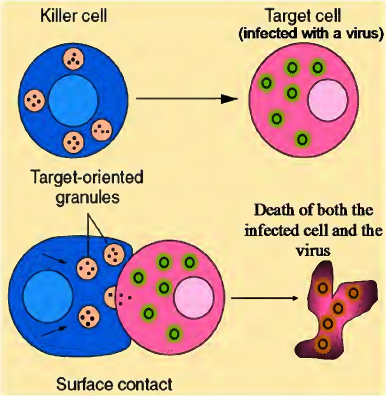

Figure 21.28: In this diagram, a killer T cell recognizes a body cell infected with a virus. After the killer T cell makes contact with the infected cell, it releases poisons that cause the infected cell to burst. This kills both the infected cell and the viruses inside it. (27)

memory cells are ready to start multiplying. They will quickly produce a new army of B or T cells to fight the pathogen. They are prepared to launch a faster, stronger attack than the first time the pathogen invaded the body. As a result, the immune system will be able to destroy the pathogen before it can cause an infection. Being able to resist a pathogen in this way is called **immunity**.

Immunity can also come about through vaccination. **Vaccination** is deliberate exposure to a pathogen in order to bring about immunity without causing disease. In vaccination, the pathogen is usually injected under the skin. However, only part of the pathogen is injected, or a weak or dead pathogen is used. This results in an immune response without causing illness. Diseases you have probably been vaccinated against include measles, mumps, and chicken pox.

Lesson Summary

- The immune system includes lymph organs, lymph vessels, lymph, and lymph nodes.
- B cells produce antibodies against pathogens in the blood and lymph.
- Killer T cells destroy body cells infected with pathogens.
- Immunity is the ability to resist a particular pathogen.
- Vaccination is deliberate exposure to a pathogen in order to bring about immunity.

Review Questions

1. What are lymphocytes?
2. Describe lymph.
3. What is an antigen?
4. What organ produces B cells and T cells?
5. Define immunity.
6. Some children with frequent sore throats have an operation to remove their tonsils. Why might removing the tonsils lead to fewer sore throats?
7. How are an antigen and antibody like a lock and key?
8. Explain how killer T cells fight pathogens.
9. Helper T cells do not produce antibodies or destroy infected cells. Why are they necessary for immune responses?
10. If you have been vaccinated against measles, you are unlikely to ever have the disease, even if you are exposed to the measles virus. Why?

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Vocabulary

antibody Large, Y-shaped protein that binds with an antigen.

antigen Any protein that triggers an immune response; unlike any protein that the body makes.

immune response The specific third line of defense against pathogens; involves the immune system.

immune system System that protects the body from pathogens and other causes of disease.

immunity Ability to resist a pathogen because cells of the immune system "remember" the pathogen from a previous infection or vaccination.

lymph Yellowish fluid that leaks out of tiny vessels into spaces between cells in tissues.

lymph nodes

Small, oval structures located along lymphatic vessels that filter pathogens from lymph.

lymphocytes Type of white blood cells involved in an immune response.

vaccination Deliberate exposure to a pathogen in order to bring about immunity without causing disease.

Points to Consider

- What do you think is the role of the reproductive system?
- Do you know what organs and other structures make up the reproductive system?
- Do you know how they differ between males and females?

Image Sources

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Chapter 22

Reproductive Systems and Life Stages

22.1 Lesson 22.1: Male Reproductive System

Lesson Objectives

- State the functions of the male reproductive system.
- Identify and describe the male reproductive organs.
- Explain what sperm are and how they are produced.

Check Your Understanding

- How does sexual reproduction occur?
- What happens during meiosis?
- What are gametes?

Introduction

Dogs have puppies. Cats have kittens. All organisms reproduce, including humans. Like other mammals, humans have a body system that controls reproduction. It is called the reproductive system. It is the only human body system that is very different in males and females. The male and female reproductive systems have different organs and different functions.

Functions of the Male Reproductive System

The male reproductive system has two main functions: producing sperm and secreting testosterone. **Sperm** are male gametes. Gametes were introduced in the *Cell Division, Reproduction, and DNA* chapter. Gametes are sex cells that may unite to form a new organism. Sperm form when certain cells in the male reproductive system divide by meiosis. Mature males produce millions of sperm each day.

Testosterone is the main sex hormone in males. You read about hormones in the *Controlling the Body* chapter. Hormones are chemicals that control many body processes. Testosterone has two major roles.

- During the teen years, testosterone causes the reproductive organs to mature. It also causes other male traits to develop. For example, it causes hair to grow on the face.
- During adulthood, testosterone is needed for a man to produce sperm.

Testosterone is not the only sex hormone that males secrete. Males also secrete small amounts of estrogen, the main female sex hormone. Scientists think that estrogen is needed for normal sperm production in males.

Male Reproductive Organs

The male reproductive organs include the penis, testes, and epididymis. These organs are shown in **Figure** 22.1. The figure also shows other parts of the male reproductive system.

The **penis** is a cylinder-shaped organ. It contains the urethra. The urethra is a tube that carries urine out of the body. The role of the urethra in reproduction is to carry sperm out of the body.

The two **testes** (singular, testis) are egg-shaped organs. They produce sperm and secrete testosterone. The testes are contained in the scrotum. As you can see from **Figure** 22.1, the scrotum is a sac that hangs down outside the body. The scrotum also contains the epididymis.

The **epididymis** is a tube that is about 6 meters (20 feet) long in adults. It is tightly coiled, so it fits inside the scrotum. It rests on top of the testes. The epididymis is where sperm mature. The epididymis also stores sperm until they leave the body.

Other parts of the male reproductive system include the vas deferens and prostate gland. Both of these structures are shown in **Figure** 22.1. The vas deferens is a tube that carries sperm from the epididymis to the urethra. The prostate gland secretes a fluid that mixes with sperm to help form semen. **Semen** is a milky liquid that passes through the urethra and out of the body.

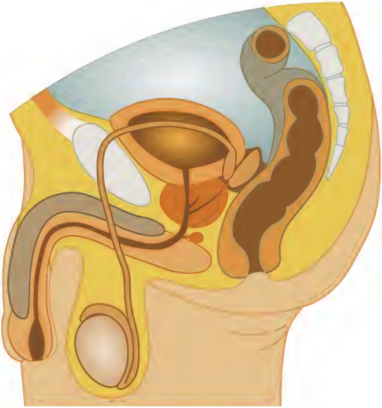

Figure 22.1: This drawing shows the organs of the male reproductive system. It shows the organs from the side. Find each organ in the drawing as you read about it in the text. (10)

Sperm and Sperm Production

Sperm are tiny cells. In fact, they are the smallest cells in the human body. A sperm cell is shown in **Figure** 22.2. What do you think a sperm cell looks like? Some people think that it looks like a tadpole. Do you agree?

Figure 22.2: This drawing of a sperm shows its main parts. What is the role of each part? How do you think the shape of the sperm might help it to "swim"? (15)

Sperm

A sperm has three main parts. They are the head, midpiece, and tail. Each part plays an important role in reproduction.

- The head of the sperm contains the nucleus. Within the nucleus are the chromosomes. Remember, in humans, the nucleus of the sperm cell contains 23 chromosomes. The head also contains enzymes that help the sperm break through the cell membrane of an egg. You will read more about this process in Lesson 3.
- The midpiece of the sperm is packed with mitochondria. Mitochondria are structures in cells that produce energy (discussed in the *Cells and Their Structures* chapter). Sperm use the energy produced in the midpiece to move.
- The tail of the sperm rotates like a propeller. This pushes the sperm forward. A sperm can travel about 0.8 meters (30 inches) per hour. This may not sound very fast, but don't forget how small a sperm is. For its size, a sperm moves about as fast as you do when you walk briskly. You can see how a sperm's tail rotates to propel it forward by watching the animation at http://www.stanford.edu/group/Urchin/sperm-1.htm.

Sperm Production

The process of producing sperm starts in the testes and ends in the epididymis. The entire process takes up to two months. It begins when special cells in the testes undergo mitosis. The special cells make identical copies of themselves that continue to go through the process of sperm formation, while the original cells remain to produce more sperm in the future. The copies of the original cells divide by meiosis, producing cells called spermatids. The

spermatids have half the number of chromosomes as the original cell. However, they are still immature and cannot move on their own.

The spermatids are transferred from the testes to the epididymis. In the epididymis, they gradually become mature. They grow a tail. They also lose some of the cytoplasm from the head. Once they mature, they are able to "swim." The mature sperm are stored in the epididymis until it is time for them to leave the body. To watch an animation of all these steps of sperm production, visit http://www.pennhealth.com/health_info/ animationplayer/sperm_production.html

Sperm leave the epididymis through the vas deferens (**Figure** 22.1). As they travel through the vas deferens, they pass by the prostate and other glands. The sperm mix with fluids from these glands, forming semen. The semen travels through the urethra and leaves the body through the penis. A teaspoon of semen may contain as many as 500 million sperm!

Lesson Summary

- The main functions of the male reproductive system are to produce sperm and secrete testosterone.
- Male reproductive organs include the penis, testes, and epididymis.
- Sperm are male gametes that form in the testes and mature in the epididymis.

Review Questions

Knowledge and Comprehension

1. What are sperm?
2. What is the main sex hormone in males?
3. Which organs produce sperm and secrete testosterone?
4. What is the function of the tail of a sperm?
5. Arrange the following structures in the order that sperm pass through them: urethra, epididymis, vas deferens.
6. Explain what testosterone does in males.
7. Contrast the roles of the testes and penis in reproduction.
8. How do sperm differ from semen? How are the two related?
9. Explain why sperm production is not completed when spermatids have been produced.
10. Why is the epididymis needed for reproduction in males?

Further Reading / Supplemental Links

CK-12.org, High School Biology, Chapter 40, Lesson 1.

- http://www.eurekalert.org/pub_releases/2007-05/wuso-eii051007.php
- http://www3.interscience.wiley.com/journal/118662957/abstract?CRETRY=1&SRETRY=0
- http://www.kidshealth.org/parent/general/body_basics/male_reproductive.html
- http://www.livescience.com/health/060208_hyper_sperm.html
- http://www.nytimes.com/2007/06/12/science/12angi.html
- http://en.wikipedia.org/wiki/Vas_deferens
- Alex Firth. *What's Happening to Me?: Boys Edition.* Usborne Books, 2007.
- Frank C. Hawkins and Greta Laube. *The Boy's Body Guide: A Health and Hygiene Book for Boys 8 and Older.* Boys Guide Books, 2007.
- Kate G. Pfeifer. *American Medical Association's Boy's Guide to Becoming a Teen.* Jossey-Bass, 2006.

Vocabulary

epididymis Male reproductive organ where sperm mature and are stored until they leave the body.

penis Male reproductive organ that carries urine and sperm out of the body.

semen Milky liquid that contains sperm and secretions of glands; passes through the urethra and out of body.

sperm Male gametes or sex cells.

testosterone Main sex hormone in males.

testes Male reproductive organs that produce sperm and secrete testosterone.

Points to Consider

- The production of sperm by males is just one part of the process of human reproduction.
- The production of eggs by females is another part of the process.
- Do you know which organs in females produce eggs? Do you know how eggs are produced?
- Besides producing eggs, what do you think might be other functions of the female reproductive system?

22.2 Lesson 22.2: Female Reproductive System

Lesson Objectives

- State the functions of the female reproductive system.
- Identify and describe the female reproductive organs.
- Explain what eggs are and how they are produced.
- Outline the monthly cycle of the female reproductive system.

Check Your Understanding

- Where is the pituitary gland?
- What is its role in the endocrine system?
- What are FSH and LH?

Introduction

Most of the male reproductive organs are outside the body. In contrast, most of the female reproductive organs are inside the body. The male and female organs also look very different. They have different functions, as well. However, two of the functions of the female reproductive system parallel the functions of the male reproductive system. Like the male system, the female system produces gametes and a major sex hormone.

Functions of the Female Reproductive System

One function of the female reproductive system is to produce eggs. **Eggs** are female gametes, and they are produced in the ovaries. Mature females release only one egg at a time. Eggs actually form before birth. However, they do not fully develop until later in life. This will be discussed later in this lesson.

Another function of the female system is to secrete estrogen. **Estrogen** is the main sex hormone in females. Estrogen has two major roles.

- During the teen years, estrogen causes the reproductive organs to mature. It also causes other female traits to develop. For example, it causes the breasts to grow.
- During adulthood, estrogen is needed for a woman to release eggs.

The female reproductive system has another important function. It supports a baby as it develops before birth. It also gives birth to the baby at the end of pregnancy.

Female Reproductive Organs

The female reproductive organs include the vagina, uterus, Fallopian tubes, and ovaries. These organs are shown in **Figure** 22.3. The breasts are not shown in this figure. They are not considered reproductive organs. However, they are involved in reproduction. They contain mammary glands that secrete milk to feed a baby. The milk leaves the breast through the nipple when the baby sucks on it.

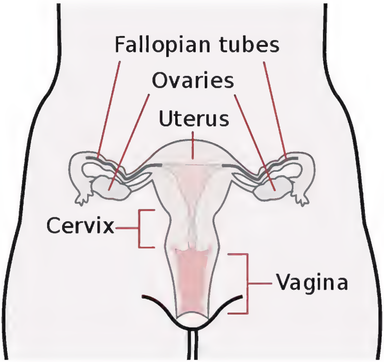

Figure 22.3: This drawing shows the organs of the female reproductive system. It shows the organs from the front. Find each organ in the drawing as you read about it in the text. (17)

The **vagina** is a cylinder-shaped organ. One end of the vagina opens at the surface of the body. The other end joins with the uterus. During sexual intercourse, sperm may deposited in the vagina. The sperm move through the vagina and into the uterus. During birth, a baby passes from the uterus through the vagina to leave the body.

The **uterus** is a hollow organ with muscular walls. The narrow part of the uterus where it connects with the vagina is called the **cervix**. The uterus is where a baby develops until birth. The walls of the uterus expand as the baby grows. The muscular walls of the uterus push the baby out during birth.

The two **ovaries** are small, oval organs on opposite sides of the uterus. Each ovary contains thousands of eggs. The eggs do not fully develop until a female has gone through puberty. About once a month, an egg completes its development and is released by the ovary. The

ovaries also secrete estrogen.

The two **Fallopian tubes** are narrow passages that open off the uterus. Each tube reaches one of the ovaries. However, the tubes are not attached to the ovaries. Notice in **Figure** 22.3 that the end of each Fallopian tube by the ovary has "fingers." They sweep an egg into the Fallopian tube. Then the egg passes through the Fallopian tube to the uterus.

Eggs and Egg Production

When a baby girl is born, her ovaries contain all the eggs they will ever produce. However, the eggs are not fully developed. They develop only after she starts having menstrual periods at about age 12 or 13. Just one egg develops each month. This usually continues until a woman is in her 40s.

Eggs

Eggs are very big cells. In fact, they are the biggest cells in the human body. An egg is about 30 times as wide as a sperm cell. It is large enough to see without a microscope. Like a sperm cell, the egg contains a nucleus with half the number of chromosomes as other body cells. Unlike a sperm cell, the egg contains a lot of cytoplasm, which is why it is so big. The egg also does not have a tail.

Egg Production

Egg production takes place in the ovaries. The process occurs in several steps. It begins before a girl is born. Before birth, special cells in the ovaries undergo mitosis. The daughter cells then start to divide by meiosis. However, they only go through the first of the two cell divisions of meiosis at that time. They remain in this state until the female has gone through puberty.

In a mature female, an egg develops in an ovary about once a month. The drawing in **Figure** 22.4 shows how this happens. As you can see from the figure, the egg is enclosed in a nest of cells called a **follicle**. The follicle and egg grow larger and go through other changes. After a couple of weeks, the egg bursts out of the follicle and through the wall of the ovary. This is called **ovulation**. The moving fingers of the nearby Fallopian tube sweep the egg into the tube. The empty follicle then changes into a structure called a **corpus luteum**.

KEY:

1. Undeveloped eggs
2. Egg and follicle developing
3. Egg and follicle developing

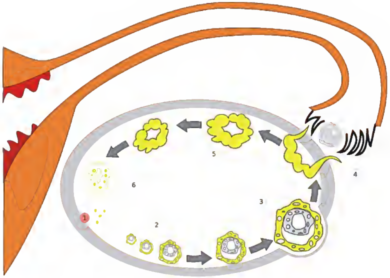

Figure 22.4: This diagram shows how an egg and its follicle develop in an ovary. After it develops, the egg leaves the ovary and enters the Fallopian tube. The empty follicle becomes a structure called a corpus luteum. (8)

4. Ovulation
5. Empty follicle changing into corpus luteum
6. Corpus luteum breaking down

If a sperm unites with the egg while it is passing through the Fallopian tube, the egg finally completes meiosis. This results in two daughter cells that are different in size. The smaller cell is called a polar body. It contains very little cytoplasm. It soon breaks down and disappears. The larger cell is the egg. It contains most of the cytoplasm. You can watch an animation of all the steps of egg production at http://www.pennhealth.com/health_info/animationplayer/egg_production.html

The Monthly Cycle

Egg production by the ovary is part of the menstrual cycle. The **menstrual cycle** is a series of changes in the reproductive system of mature females that repeats every month. It includes events that occur in the uterus as well as the ovary.

Menstruation

While the egg and follicle are developing in the ovary, tissues are building up inside the uterus. The uterus develops a thick lining that is rich in tiny blood vessels. This prepares the uterus to receive an egg. If a sperm does *not* unite with the egg in the Fallopian tube, the lining of the uterus breaks down. Blood and other tissues from the lining are shed from the uterus. They pass through the vagina and out of the body. This is called **menstruation**. Menstruation is also called a menstrual period. It lasts about 4 days, on average. When the menstrual period ends, the cycle repeats.

Some people think that the average length of a menstrual period is the same as the "normal" length. They assume that shorter or longer menstrual periods are not normal. In fact, menstrual periods can vary from 1 to 8 days in length. Such variation is usually normal. The length of the overall menstrual cycle can also vary. The average length of the cycle is about 28 days, but there is no "normal" cycle length.

Hormones and the Menstrual Cycle

Hormones control the events of the menstrual cycle. The hormones are estrogen, progesterone, LH, and FSH. The ovaries secrete estrogen and progesterone. The pituitary gland secretes LH and FSH (see the *Controlling the Body* chapter).

The events of the menstrual cycle, including how hormone levels change throughout the cycle, are shown in **Figure** 22.5. As the figure indicates, a menstrual cycle begins with menstruation. When menstruation ends, the ovaries start secreting more estrogen. Estrogen causes the lining of the uterus to build up, which prepares the uterus to receive an egg. It also causes the pituitary gland to secrete FSH. FSH, in turn, causes an egg and follicle to mature in an ovary. The maturing follicle secretes even more estrogen. When estrogen reaches a certain level, it causes the pituitary gland to release a surge of LH. The LH surge causes ovulation. It also causes the empty follicle to develop into a corpus luteum. The corpus luteum secretes progesterone. This hormone maintains the lining of the uterus so it doesn't break down.

What happens next depends on whether a sperm unites with the egg. If it does, the egg secretes a hormone that prevents the corpus luteum from breaking down. The corpus luteum, in turn, keeps secreting progesterone. This maintains the lining of the uterus. What happens if a sperm does *not* unite with the egg is shown in **Figure** 22.5. The corpus luteum breaks down and stops secreting progesterone. As a result, the lining of the uterus is no longer maintained. It breaks down and is shed from the uterus. Thus, menstruation begins and the cycle repeats.

Dr. JoAnne Richards is a world-famous endocrinologist. An endocrinologist is a scientist that studies hormones. Dr. Richards helped discover how FSH and LH control the growth of follicles and ovulation. She has received many awards and honors for her work, including

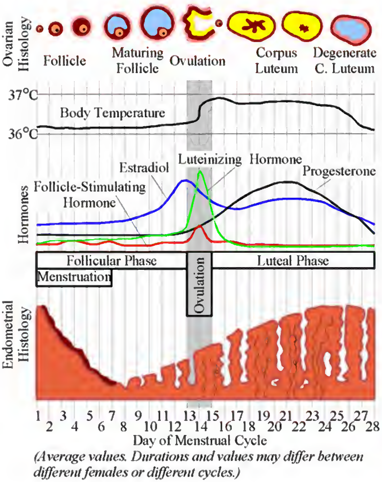

Figure 22.5: This diagram shows the changes that normally occur in the ovary and uterus during the menstrual cycle. It also shows how hormone levels change during the cycle. The menstrual cycle begins with menstruation. Ovulation occurs about half way through the cycle. (1)

the 2007 Women in Endocrinology Award.

Lesson Summary

- The functions of the female reproductive system are to produce eggs, secrete estrogen, and support a baby as it develops before birth.
- Female reproductive organs include the vagina, uterus, ovaries, and Fallopian tubes.
- Eggs are female gametes that form in the ovaries and are released into the Fallopian tubes.
- The menstrual cycle is a monthly cycle of changes in the ovaries and uterus. It includes ovulation and menstruation.

Review Questions

1. What are eggs?
2. What is the main sex hormone in females?
3. List the two major roles of estrogen in females.
4. What are the functions of the uterus in female reproduction?
5. Describe ovulation.
6. Compare and contrast eggs and sperm.
7. Explain how an egg develops in an ovary of a mature female.
8. Explain why menstruation occurs if a sperm does *not* unite with the egg that is released by an ovary.
9. How do LH and FSH control changes in the ovary during the menstrual cycle?
10. Explain why the lining of the uterus breaks down if a sperm does *not* unite with an egg. What role does progesterone play?

Further Reading / Supplemental Links

CK-12.org, High School Biology, Chapter 40, Lesson 2.

- Kate Pfeifer. *American Medical Association's Girl's Guide to Becoming a Teen*. Jossey-Bass, 2006.
- Sophie Waters. *The Female Reproductive System (Girl's Health)*. Rosen Publishing Group, 2007.
- Susan Meredith. *What's Happening to Me?: Girls Edition*. Usborne Books, 2006.
- http://www.bcm.edu/mcb/?PMID=7691
- http://www.kidshealth.org/parent/general/body_basics/female_reproductive_system.html
- http://www.merck.com/mmhe/sec22/ch241/ch241e.html
- http://www.nytimes.com/2007/06/12/science/12angi.html

- http://www.women-in-endo.org/awards/#richards
- http://en.wikipedia.org/wiki

Vocabulary

cervix Narrow part of the uterus where it connects with the vagina.

corpus luteum Structure that develops from a follicle after the egg bursts out of the follicle and through the ovary wall during ovulation.

eggs Female gametes or sex cells.

estrogen Main sex hormone in females.

fallopian tubes Female reproductive organs through which eggs pass to reach the uterus and where an egg may unite with a sperm.

follicle Nest of cells in an ovary that enclose an egg; protects egg during maturation prior to ovulation.

menstrual cycle Monthly cycle of changes that occur in the uterus and ovaries.

menstruation Monthly shedding of the lining of the uterus through the vagina; also called a menstrual period.

ovaries Female reproductive organs that produce eggs and secrete estrogen.

ovulation Release of an egg by an ovary.

vagina Female reproductive organ where sperm are deposited and through which a baby passes to leave the mother's body during birth.

uterus Female reproductive organ where a baby develops until birth.

Points to Consider

- After an egg is released, what must occur in order for reproduction to proceed? Do you know what the next step is called? Do you know where it takes place?

22.3 Lesson 22.3: Reproduction and Life Stages

Lesson Objectives

- Explain how fertilization occurs.
- Identify major events of pregnancy and childbirth.
- List important developments of infancy and childhood.
- Outline changes that occur during adolescence.
- Describe the stages of adulthood.

Check Your Understanding

- What are sperm and eggs?
- How many chromosomes do sperm and eggs have?
- What is the role of sex hormones during the teen years?

Introduction

The sperm and egg pictured in Figure 1 below don't look anything like a human baby. After these two gametes unite, however, they will develop into a human being. How does a single cell become a complex organism made up of billions of cells? Keep reading to find out.

Fertilization and Implantation

Sexual reproduction occurs when an egg unites with a sperm. This is called **fertilization**. Sperm are deposited in the vagina during sexual intercourse. They "swim" through the uterus and enter a Fallopian tube. This is where fertilization normally takes place. A sperm that is about to enter an egg is shown in **Figure** 22.6. If the sperm breaks through the egg's membrane, it will cause changes in the egg that keep other sperm out. It will also trigger the egg to complete meiosis. Recall that meiosis begins long before an egg is released from an ovary.

The sperm and egg each have only half the number of chromosomes as other cells in the body. Therefore, when they unite, they form a cell with the full number of chromosomes. The cell they form is called a **zygote**. The zygote slowly travels down the Fallopian tube to the uterus. As it travels, it divides by mitosis many times. It forms a hollow ball of cells. After the ball of cells reaches the uterus, it embeds in the lining of the uterus. This is called **implantation**. It usually occurs about a week after fertilization.

Figure 22.6: This sperm is ready to penetrate the membrane of this egg. Notice the difference in size of the sperm and egg. What will happen if the sperm manages to break through the egg's membrane? (12)

Pregnancy and Childbirth

Once the ball of cells implants in the uterus, it is called an **embryo**. The embryo stage lasts until the end of the 8^{th} week after fertilization. After that point until birth, the developing baby is called a **fetus**. To see how an embryo and fetus grow and develop, go to http://www.pennhealth.com/health_info/animationplayer/fetal_dvlp_tool.html

Growth and Development of the Embryo

During the embryo stage, the baby grows in size. It also develops different types of cells and organs. Cells of different types start to develop by the 3^{rd} week after fertilization. They form structures that suit them for different roles in the body. Cells that will form muscles and skin, for example, start to develop at this time.

In 2004, French scientist Nicole Le Douarin won the first Pearl Meister Greengard Prize in Science. This award has been called the "American Nobel Prize for women scientists." Dr. Le Douarin received the prize for developing a method to follow the path of individual cells during the development process. This, in turn, has helped scientists discover how different organs develop.

During the 4^{th} week after fertilization, body organs begin to form. By the end of the 8th week, all the major organs have started to develop. Figure 2 shows some of the changes that take place during the 4^{th} and 8^{th} weeks. Look closely at the two embryos in the figure. Do you think that the older embryo looks more human? Notice that it has arms and legs and

lacks a tail. Its facial features have also started to form. The older embryo is much bigger, as well.

The pictures in the **Table** (22.1) show how a developing baby looks, beginning at 4 weeks after fertilization and ending at 38 weeks after fertilization. The pictures show the baby at the same size at each stage. However, the actual size increases greatly during development. The length of the baby at each stage is given in the figure. Read the information in the boxes to learn what organs and other features have developed by each stage.

Table 22.1: **Human Embryo**

Image	Developmental characteristics
4 Weeks *Length:* 5.0 mm 	• Facial features are just starting to form. • Tail is present. • Legs have formed, and arm buds have appeared. • Heart is partly formed and begins to beat. • Spinal cord and brain have started to develop. • Most other organs have started to form, including the liver, pancreas, gall bladder, spleen, and lungs.
8 Weeks *Length:* 3.2 cm 	• Facial features are starting to look human, and external ears and eyes are beginning to form. • Tail has disappeared. • Arms have developed; fingers and toes are starting to form. • Heart is well developed. • Digestive system is developing rapidly but does not yet function. • Cartilage and bones have started to form, and muscles are developing.

Table 22.1: (continued)

Image	Developmental characteristics
	• Internal ears and eyes are developing. • Nails have appeared on fingers and toes. • Reproductive organs have developed into either male or female organs. • Brain is developing rapidly. • Lungs are developing, but breathing is not yet possible. • Fetus is active, and mother may start to feel fetus moving.
	• Eyes are fully formed. • Eyelashes and eyebrows are present. • Hair has started to grow on the head. • Lungs are almost completely developed but unable to breathe on their own. • Muscles and bones are developing rapidly. • Muscle tone is increasing.
	• All organs are completely formed and functioning. • Fat is accumulating quickly. • Weight is increasingly rapidly. • Fetus is fully developed and ready to be born.

Growth and Development of the Fetus

Table (22.1) also shows changes that take place after the embryo becomes a fetus. Compare the 18^{th}-week fetus with the 8^{th}-week embryo. Some of the differences between them are obvious. For example, the fetus has ears and eyelids. Its fingers and toes are also fully formed. The fetus even has fingernails and toenails. In addition, the reproductive organs have developed along male or female lines. The brain and lungs are also developing quickly. The fetus has started to move around inside the uterus. This is usually when the mother first feels the fetus moving.

By the 28^{th} week, the fetus is starting to look much more like a baby. Eyelashes and eyebrows are present. Hair has started to grow on the head. The body of the fetus is also starting to fill out, as muscles and bones develop. Babies born after the 28^{th} week are usually able to survive. However, they need help breathing because their lungs are not yet fully mature.

During the last several weeks of the fetal period, all of the organs become mature. The most obvious change, however, is an increase in body size. The fetus rapidly puts on body fat and gains weight during the last couple of months. Compare the pictures in **Table** (22.1) of the fetus at 28 weeks and 38 weeks. Do you see how much chubbier the older fetus looks? By the end of the 38^{th} week, all the organs are functioning, and the fetus is ready to be born. This is when birth normally occurs.

The Amniotic Sac and Placenta

During pregnancy, other structures also develop inside the mother's uterus. They are the amniotic sac, placenta, and umbilical cord. They are shown in **Figure** 22.7.

The **amniotic sac** is a membrane that surrounds the fetus. It is filled with water and dissolved substances. Imagine placing a small plastic toy inside a balloon and then filling the balloon with water. The toy would be cushioned and protected by the water. It would also be able to move freely inside the balloon. The amniotic sac and its fluid are like a water-filled balloon. They cushion and protect the fetus. They also let the fetus move freely inside the uterus.

The **placenta** is a spongy mass of blood vessels. Some of the vessels come from the mother. Some come from the fetus. The placenta is attached to the inside of the mother's uterus. The fetus is connected to the placenta by a tube called the **umbilical cord**. The cord contains two arteries and a vein. Substances pass back and forth between the mother's and fetus's blood through the placenta and cord. Oxygen and nutrients pass from the mother to the fetus. Carbon dioxide passes from the fetus to the mother.

It is important for the mother to eat plenty of nutritious food during pregnancy. She must take in enough nutrients for the fetus as well as for herself. She needs extra Calories, proteins, and lipids. She also needs more vitamins and minerals. In addition to eating well, the mother must avoid substances that could harm the embryo or fetus. These include alcohol, illegal

Figure 22.7: This fetus is 38 weeks old and ready to be born. Surrounding the fetus is the fluid-filled amniotic sac. The placenta and umbilical cord are also shown here. They provide a connection between the mother's and fetus's blood for the transfer of nutrients and gases. (9)

drugs, and some medicines. It is especially important for her to avoid these substances during the first eight weeks after fertilization. This is when all the major organs are forming. Exposure to harmful substances during this time could have major effects on the developing body systems.

Childbirth

During **childbirth**, a baby passes from the uterus, through the vagina, and out of the mother's body. Childbirth usually starts with the amniotic sac breaking. Then the muscles of the uterus start contracting. The contractions get stronger and closer together. They may go on for hours. Eventually, the contractions squeeze the baby out of the uterus. Once the baby enters the vagina, the mother starts pushing. She soon pushes the baby through the vagina and out of her body.

As soon as the baby is born, the umbilical cord is cut. After the cord is cut, the baby can no longer get rid of carbon dioxide through the cord and placenta. As a result, carbon dioxide builds up in the baby's blood. This triggers the baby to start breathing. The amniotic sac and placenta pass through the vagina and out of the body shortly after the birth of the baby.

Infancy and Childhood

The first year after birth is called **infancy**. Infancy is a period of very fast growth. During infancy, the baby doubles in length and triples in weight. Other important changes also occur during infancy.

- The baby teeth start to come in, usually at about six months of age (**Figure** 22.8).
- The baby starts smiling, paying attention to other people, and grabbing toys.
- The baby begins making babbling sounds. By the end of the first year, the baby is starting to say a few words, such as "Mama" and "Dada."
- The baby learns to sit, crawl, and stand. By the end of the first year, the baby may be starting to walk.

Figure 22.8: This baby is six months old, and his baby teeth have started to come in. Babies often chew on toys or other objects when they are getting new teeth. They may even chew on their toes, as this baby is doing. Putting things in their mouth also helps them learn about the world. What do you think this baby might be learning by putting his toes in his mouth? (5)

Childhood begins after the baby's first birthday and continues until the teens. Between one and three years of age, a child is called a toddler. During the toddler stage, growth is still rapid, but not as fast as it was during infancy. A toddler learns many new words. The child even starts putting together words in simple sentences. Motor skills also develop quickly during this stage. By age three, most children can run and climb steps. They can hold crayons and scribble with them. They can also feed themselves. Most children are toilet trained by age three, as well.

From age three until the teens, growth is slower. The body also changes shape. The arms and legs get longer relative to the trunk. Children continue to develop new motor skills. For example, many young children learn how to ride a tricycle and then a bicycle. Most also learn how to play games and sports (**Figure** 22.9). By age six, children start losing their baby teeth. Their permanent teeth begin coming in to replace them. They also start school and learn how to read and write. They develop friendships and become less dependent on their parents.

Figure 22.9: Children develop better motor skills as they get older. What motor skills is this child demonstrating by playing soccer? (6)

Puberty and Adolescence

The reproductive organs are present at birth. However, they grow very little during childhood. They do not mature and start functioning until puberty.

Puberty

Puberty is the stage of life when a child becomes sexually mature. Puberty lasts from about 12 to 18 years of age in boys and from about 10 to 16 years of age in girls.

The age when puberty begins varies from one child to another. Children that begin puberty much earlier or later than their peers may feel self-conscious. They may also worry that something is wrong with them. Usually, an early or late puberty is perfectly normal. If you have concerns about puberty, tell a parent. Your doctor can check to make sure you are developing normally.

In boys, puberty begins when LH from the pituitary gland triggers the testes to secrete testosterone. Testosterone causes the penis and testes to grow. Along with FSH from the pituitary gland, testosterone also causes the testes to start making sperm. Testosterone leads to the growth of pubic and facial hair, as well. In addition, it causes the shoulders to broaden and the voice to deepen.

In girls, puberty begins when LH from the pituitary gland triggers the ovaries to secrete estrogen. Estrogen causes the uterus and ovaries to grow. Along with FSH from the pituitary gland, estrogen also causes the ovaries to start releasing eggs. Estrogen causes the menstrual cycle to begin, as well. In addition, it leads to the growth of pubic hair. Estrogen also causes the hips to widen and the breasts to develop.

Teen girls that are athletic may develop a condition called the female athlete triad. It occurs when very active girls eat too few Calories to provide all the energy they need. Lack of energy leads to low levels of estrogen. As a result, girls do not begin menstruating or their menstrual periods stop. They also develop osteoporosis. This is a serious disorder in which bones lose minerals and can break easily. The female athlete triad may have lifelong effects on health. It can even be fatal. It requires medical treatment and an increase in Calories in the diet.

Boys and girls are close to the same height during childhood. In both boys and girls, growth in height and weight is very fast during puberty. However, boys grow faster than girls during puberty. Their period of rapid growth also lasts longer. As a result, by the end of puberty, boys are an average of 10 centimeters taller than girls.

Adolescence

Adolescence is the period of life between the start of puberty and the beginning of adulthood. Adolescence includes the physical changes of puberty. It also includes may other changes. During adolescence,

- teens develop new thinking abilities. For example, they can think about abstract ideas such as freedom. They are also better at thinking logically. They are usually better at solving problems, as well.
- teens try to establish a sense of who they are as individuals. They may try to become more independent from their parents. Most teens also have emotional ups and downs. This is partly due to changing hormone levels.
- teens usually spend much more time with peers than family members (**Figure** 22.10). The opinions of their peers are also very important to them. Most teens feel pressured to dress and act as their peers do in order to be accepted.

Figure 22.10: These teens are good friends. Like most teens, they spend more time with one another than they do with family members. These teens are volunteering at their local library. What do you enjoy doing with your friends? (3)

Adulthood

When is a person considered an adult? That depends. Most teens become physically mature by the age of 16 or so. However, they are not adults in a legal sense until they are older. For example, in the U.S., you must be 18 to vote. You must be 21 to sign legal contracts. Once adulthood begins, it can be divided into three stages. The stages are early, middle, and late adulthood.

Early Adulthood

Early adulthood starts at age 18 or 21. It continues until the mid-30s. During early adulthood, people are at their physical peak. They are also usually in good health. The ability to reproduce is greatest during early adulthood, as well. This is the stage of life when most people complete their education. They are likely to begin a career or take a full time job. Many people also marry and start a family during early adulthood.

Middle Adulthood

Middle adulthood begins in the mid-30s. It continues until the mid-60s. During middle adulthood, people start to show physical signs of aging. Their hair gradually turns gray. Their skin develops wrinkles. The risk of health problems also increases during middle

adulthood. For example, heart disease, cancer, and diabetes become more common during this time. This is the stage of life when people are most likely to achieve career goals. Their children also grow up and may leave home during this stage.

Late Adulthood

Late adulthood begins in the mid-60s. It continues until death. This is the stage of life when most people retire from work. They are also likely to reflect on their life. They may focus on their grandchildren. During late adulthood, people decline in physical abilities. For example, they usually have less muscle tone and slower reflexes. Their immune system also doesn't work as well as it did. As a result, they have a harder time fighting diseases like flu. The risk of developing diseases such as heart disease and cancer continues to rise. Another health problem that is common in late adulthood is osteoporosis. Arthritis is also common. In arthritis, joints wear out and become stiff and painful. As many as one in four late adults may develop Alzheimer's disease. In this disease, brain changes cause mental abilities to decline steadily. Exercising the body and brain, and maintaining social connections can alleviate some of these effects. The various stages of adulthood discussed are pictured in **Figure** 22.11.

Despite problems such as these, many people remain healthy and active into their 80s or even 90s. Do you want to be one of them? Then adopt a healthy lifestyle now and follow it for life. Doing so will increase your chances of staying healthy and active to an old age.

Lesson Summary

- Fertilization occurs when an egg unites with a sperm to form a zygote.
- A zygote develops into an embryo and then a fetus. This occurs as cells divide, different types of cells develop, and organs form.
- An individual grows rapidly and develops new abilities during infancy and childhood.
- A child becomes sexually mature and changes in many other ways during adolescence.
- Adulthood is divided into the stages of early, middle, and late adulthood. Each stage is associated with different traits and concerns.

Review Questions

1. What is fertilization?
2. Define embryo and fetus.
3. At about how many weeks after fertilization is a fetus usually ready to be born?
4. Describe an embryo at the end of the 8^{th} week after fertilization.
5. How does a fetus change during the last two months before birth?
6. Explain the role of the amniotic sac and placenta during fetal development.

Figure 22.11: This family picture shows women in each of the three stages of adulthood. Which stage does each woman represent? What might you infer about each woman from her stage of adulthood? (14)

7. Why doesn't a doctor wait for a newborn baby to breathe on its own before cutting the umbilical cord?
8. Explain how pituitary hormones control puberty in boys and girls.
9. Compare and contrast puberty and adolescence.
10. Why is it difficult to say when adulthood begins?

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Vocabulary

adolescence Period of life between the start of puberty and the beginning of adulthood.

amniotic sac Fluid-filled membrane that surrounds and protects a fetus within the uterus.

childbirth Process through which a baby passes from the uterus, through the vagina, and out of the mother's body.

childhood Period between a baby's first birthday and puberty.

embryo Stage of a developing baby between implantation and the end of the 8th week after fertilization.

fertilization Union of a sperm and egg; occurs in a fallopian tube.

fetus Stage of a developing baby between the end of the 8^{th} week after fertilization and birth.

implantation Process in which the ball of cells that will become an embryo embeds in the lining of the uterus.

infancy First year of life after birth.

placenta Spongy mass of blood vessels from the mother and fetus that allows substances to pass back and forth between the mother's blood and the fetus's blood.

puberty Stage of life when a child becomes sexually mature.

umbilical cord Tube containing blood vessels that connects a fetus to the placenta.

zygote Cell that forms when a sperm and egg unite; the first cell of a new organism.

Points to Consider

- By early adulthood, most people have become sexually active. Sexual activity puts people at risk of certain diseases. Do you know what the diseases are? Do you know how they can be prevented? What are other ways of keeping the reproductive system healthy?

22.4 Lesson 22.4: Reproductive System Health

Lesson Objectives

- Describe common sexually transmitted diseases.
- Identify other reproductive system disorders.
- List ways to keep the reproductive system healthy.

Check Your Understanding

- What is a pathogen?
- What types of organisms can cause disease?
- What is cancer?

Introduction

A healthy reproductive system is important for two reasons. It is important for overall good health. It is also important for reproduction. If the reproductive system is not healthy, a person may be unable to have children. Many health problems can affect the reproductive system. They include sexually transmitted diseases and cancers. The good news is that many reproductive health problems can be prevented or cured.

Sexually Transmitted Diseases

A **sexually transmitted disease (STD)** is a disease that spreads through sexual contact. STDs are caused by pathogens. The pathogens enter the body through the reproductive organs. Many STDs also spread through body fluids such as blood. For example, a shared tattoo needle is one way an STD could spread. Some STDs can also spread from a mother to her baby during childbirth.

STDs are more common in teens and young adults than in older people. One reason is that young people are more likely to take risks. They often have the attitude, "It can't happen to me." They also may not know how STDs spread. They are likely to believe myths about STDs, like the myths in **Table** (22.2) .

Table 22.2: **Myths and Facts about STDs**

Myth	Fact
If you are sexually active with just one person, you can't get STDs.	The only way to avoid the risk of STDs is to practice abstinence from sexual activity.
If you don't have any symptoms, then you don't have an STD.	Many STDs do not cause symptoms, especially in females.
Getting STDs is no big deal, because STDs can be cured with medicine.	Only some STDs can be cured with medicine; other STDs cannot be cured.

(*Source*: http://womenshealth.about.com/od/stds/a/stdmythsvsfacts.htm)

Most STDs are caused by bacteria or viruses. STDs caused by bacteria usually can be cured with drugs called antibiotics. However, antibiotics are not effective against viruses. Therefore, viral STDs are not treated with antibiotics. Other drugs may be used to help control the symptoms of viral STDs, but they cannot be cured. Once you are have a viral STD, you are usually infected for life.

Bacterial STDs

In the U.S., **Chlamydia** is the most common STD caused by bacteria. Females are more likely than males to develop the disease. Rates of Chlamydia among U.S. females in 2006 is given in **Figure** 22.12. Rates were much higher in teens and young women than in other age groups. Chlamydia may cause a burning feeling during urination. It may also cause a discharge from the vagina or penis. However, in many cases, it causes no symptoms. As a result, people do not know they are infected. Therefore, they don't go to the doctor for help. If Chlamydia goes untreated, it may cause more serious problems in females. It may cause infections of the uterus, Fallopian tubes, or ovaries. These infections may leave a woman unable to have children.

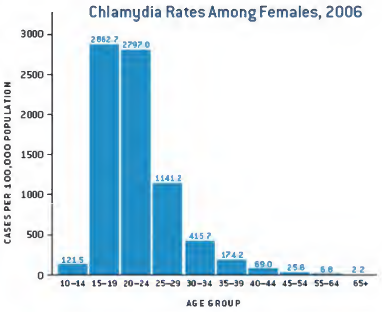

Figure 22.12: This graph shows data on the number of cases of Chlamydia in U.S. females in 2006. Which two age groups had the highest rates of Chlamydia? Why do you think rates were highest in these age groups? (7)

Gonorrhea is another common STD. Gonorrhea may cause pain during urination. It may also cause a discharge from the vagina or penis. However, some people with gonorrhea have no symptoms. As a result, they don't seek treatment. Without treatment, gonorrhea may lead to infection of other reproductive organs. This can happen in males as well as females.

Syphilis is a very serious STD. Luckily, it is less common than Chlamydia or gonorrhea. Syphilis usually begins with a small sore on the genitals. This is followed a few months later by a rash and flu-like symptoms. If syphilis is not treated, it may damage the heart, brain, and other organs. It can even cause death.

Viral STDs

Genital warts are an STD caused by human papilloma virus, or HPV. They are one of the most common STDs in teens. HPV infections cannot be cured. However, a new vaccine called Gardasil® can prevent most HPV infections in females. Many doctors recommend that females between the ages of 9 and 26 years receive the vaccine. Preventing HIV infections in females is important, because HPV can also cause cancer of the cervix.

Genital herpes is an STD caused by a virus called herpes. It is another very common STD. You can see how genital herpes is spread at http://www.sexualhealthissues.com/ms/animations/21/main.html. A related herpes virus causes cold sores on the lips (**Figure** 22.13). Both viruses cause painful blisters. In the case of genital herpes, the blisters are on the penis or membranes around the vaginal opening. The blisters go away on their own. However, the virus remains in the body. It may cause repeated outbreaks of blisters. The outbreaks are more likely when a person is under stress. There is no cure for genital herpes. However, drugs can help prevent or shorten outbreaks. Researchers are trying to find a vaccine to prevent genital herpes.

Figure 22.13: This lip blister, or cold sore, is caused by a herpes virus. The virus is closely related to the virus that causes genital herpes. The genital herpes virus causes similar blisters on the genitals. If you've ever had a cold sore, you know how painful they can be. Genital herpes blisters are also painful. (2)

Hepatitis B is a disease of the liver. It is caused by a virus called hepatitis B, which can be passed through sexual activity. Hepatitis B causes vomiting. It also causes yellowing of the skin and eyes. The disease goes away on its own in some people. Other people are sick for the rest of their life. In these people, the virus usually damages the liver. It may also

lead to liver cancer. Medicines can help prevent liver damage in these people. There is also a vaccine to prevent hepatitis B.

HIV stands for human immunodeficiency virus. It is the virus that causes AIDS. HIV and AIDS are described in the *Diseases and the Body's Defenses* chapter. HIV can spread through sexual contact. It can also spread through body fluids such as blood. There is no cure for HIV infection, and AIDS is a fatal disease, although the onset of AIDS can be significantly delayed with proper medication. Researchers are trying to find a vaccine to prevent HIV infection.

In Latin America, many women are infected with HIV. They are often treated unfairly just because they have the virus. For example, they may be rejected by their family or fired from their job. A woman from Argentina named Patricia Pérez has been working to change that. She was infected with HIV in the 1980s. Ever since then, she has been fighting for the rights of women with HIV. In 2007, Pérez was nominated for a Nobel Peace Prize for her work.

Other Reproductive System Disorders

Many disorders of the reproductive system are not STDs. They are not caused by pathogens, so they don't spread from person to person. They develop for other reasons. The disorders differ in males and females. In both genders, the disorders range from causing little more than discomfort to potentially causing death.

Disorders in Males

Most common disorders of the male reproductive system involve the testes. For example, injuries to the testes are very common. In teens, injuries to the testes most often occur while playing sports. An injury such as a strike or kick to the testes can be very painful. It may also cause bruising and swelling. However, such injuries seldom do lasting harm.

Varicocele is also quite common, especially during puberty. A varicocele is a swollen vein in the scrotum (**Figure** 22.14). A varicocele doesn't usually cause pain or other symptoms. If it does cause symptoms, it can be treated with surgery.

Another disorder of the testes is cancer. **Cancer of the testes** is most common in males aged 15 to 35. It occurs when cells in the testes grow out of control. The cells form a lump called a tumor. If detected early, cancer of the testes usually can be cured with surgery.

Disorders in Females

Disorders of the female reproductive system may affect the vagina, uterus, or ovaries. They may also affect the breasts. One of the most common disorders is **vaginitis**. This is redness and itching of the vagina. It may be due to irritation by soap or bubble bath. Another

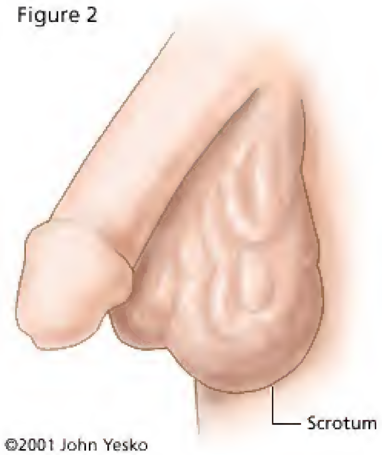

Figure 22.14: Do you see the wormlike structures under the skin of the scrotum shown here? They are swollen veins, called varicoceles. This condition usually isn't harmful. (11)

possible cause of vaginitis is a yeast infection. Yeast normally grow in the vagina. A yeast infection occurs when the yeast multiply too fast and cause symptoms. A yeast infection can be treated with medication.

Endometriosis is a disorder that may affect several organs. It occurs when tissues that normally line the uterus grow elsewhere. The tissues may grow on the uterus, ovaries, or Fallopian tubes (**Figure** 22.15). The disorder causes pain. It can also cause abnormal bleeding. In some cases, it prevents a woman from becoming pregnant. It is usually treated with hormones or surgery.

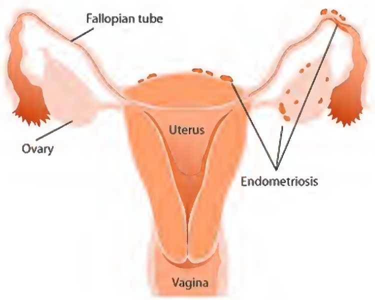

Figure 22.15: In endometriosis, tissues that normally grow inside the uterus start growing on the outside of the uterus. They may also grow on other reproductive organs. (13)

A common disorder of the ovaries is an **ovarian cyst**. A cyst is a sac filled with fluid or other material (**Figure** 22.16). An ovarian cyst is usually harmless. However, it may cause pain. Most cysts gradually disappear and do not need treatment. Very large or painful cysts can be removed with surgery.

Many teen girls have painful menstrual periods. They typically have cramping in the lower abdomen. Generally, this is nothing to worry about. Taking a warm bath or using a heating pad often helps. Exercise may help, as well. A pain reliever like ibuprofen may also be effective. If the pain is severe, a doctor can prescribe stronger medicine to relieve the pain.

The most common type of cancer in females is **breast cancer**. It occurs when cells of the breast grow out of control and form a tumor. Breast cancer is rare in teens. It becomes more common as women get older. If breast cancer is detected early, it usually can be cured with surgery.

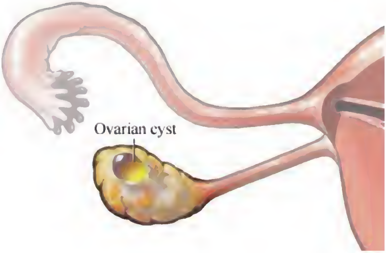

Figure 22.16: Ovarian cysts, like this one, are common. They generally do not need to be treated unless they cause symptoms. Most go away without treatment. (4)

Keeping the Reproductive System Healthy

What can you do to keep your reproductive system healthy? You can start by making the right choices for overall good health. To be as healthy as you can be, you should:

- eat a balanced diet that is high in fiber and low in fat.
- drink plenty of water.
- get regular exercise.
- maintain a healthy weight.
- get enough sleep.
- avoid using tobacco, alcohol, or other drugs.
- manage stress in healthy ways.

You should also keep the genitals clean. A daily shower or bath is all that it takes. Females do not need to use special feminine hygiene products. In fact, using them may do more harm than good. They can irritate delicate membranes.

Abstinence from sexual activity is the best way to prevent STDs. You should also avoid other behaviors that can put you at risk. Risk behavior are those that might lead to contact with another person's blood or other body fluids. For example, never get a tattoo or piercing unless you are sure that the needles have not been used before.

If you are a boy, you should always wear a protective cup when you play contact sports. Contact sports include football, soccer, and hockey. Wearing a cup will help protect the testes from injury. You should also do a monthly self-exam to check for cancer of the

testes (**Figure** 22.17). You can learn how to do the exam at http://www.5min.com/Video/Testicular-self-examination-1353

If you have any questions, ask a health care provider. It may be embarrassing, but it could save your life.

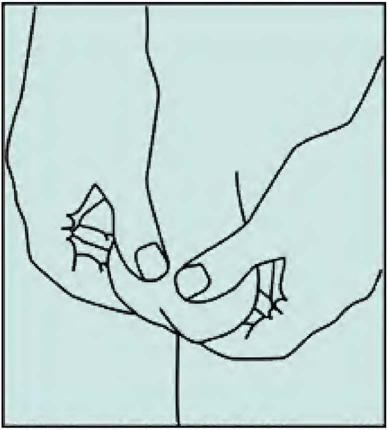

Figure 22.17: Teen boys should learn how to examine their testes for lumps that could be a sign of cancer. (16)

If you are a girl and use tampons, be sure to change them every 4 to 6 hours. Leaving tampons in too long can put you at risk of toxic shock syndrome. This is a serious condition. You should also get in the habit of doing a monthly self-exam to check for breast cancer. Although breast cancer is rare in teens, it's a good idea to start doing the exam when you are young. It will help you get to know what is normal for you. You can learn how to do the exam at http://freemedicalmovie.blogspot.com/2007/10/breast-self-exam.html

Ask a health care provider if you have any questions.

Lesson Summary

- Sexually transmitted diseases are caused by pathogens. They spread through sexual contact.
- In males, other disorders of the reproductive system include varicocele and cancer of the testes. In females, other disorders include vaginitis and breast cancer.
- One way to keep the reproductive system healthy is by making the right choices for overall good health. Other ways are keeping the genitals clean and avoiding sexual activity.

Review Questions

1. What is a sexually transmitted disease?
2. In the U.S., what is the most common STD caused by bacteria?
3. Which of the following STDs can be prevented with a vaccine? genital warts, Chlamydia, gonorrhea, hepatitis B
4. What is a varicocele?
5. What is the best way to prevent STDs?
6. Explain why bacterial STDs are treated differently than viral STDs.
7. It is especially important for females to be protected from HPV infections. Why is this the case?
8. Why should males start doing self-exams of the testes by age 15?
9. How could a person become infected with an STD without ever being sexually active?
10. Explain how girls can reduce their risk of developing toxic shock syndrome.

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- http://en.wikipedia.org/wiki

Vocabulary

breast cancer Most common type of cancer in females that occurs when cells of the breast grow out of control and form a tumor.

cancer of the testes Type of cancer common in teens and young men that occurs when cells of the testes grow out of control and form a tumor.

Chlamydia Most common STD in the U.S. that is caused by bacteria.

endometriosis Disorder in which tissues that normally line the uterus grow outside the uterus and cause pain and bleeding.

genital herpes Common STD that is caused by a virus called herpes.

genital warts Common STD that is caused by a virus called HPV.

gonorrhea Common STD that is caused by bacteria.

hepatitis B STD that damages the liver and is caused by a virus called hepatitis B.

ovarian cyst Sac filled with fluid or other material that develops in an ovary.

sexually transmitted disease (STD) Disease that spreads through sexual contact and is caused by a pathogen.

syphilis Very serious STD that is caused by bacteria.

vaginitis Redness and itching of the vagina that may be due to irritation or a yeast infection.

varicocele Swollen vein in the scrotum.

Points to Consider

- A healthy reproductive system is important if you plan to have children when you are older. The birth of children, in turn, is one of the main factors that affect the growth of a population. We turn our attention next to ecology.
- Ecology includes the study of populations. What factors do you think affect population growth? How might a rapidly growing population affect its environment?

Image Sources

(1) http://commons.wikimedia.org/wiki/Image:MenstrualCycle.png. CC-BY-SA 2.5.

(2) http://commons.wikimedia.org/wiki/Image:Herpes_labialis.jpg. Public Domain.

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Chapter 23

From Populations to the Biosphere

23.1 Lesson 23.1: Introduction to Ecology

Lesson Objectives

- Define what ecology is.
- Explain what organisms and environments are.
- Describe how organisms can interact with their environments.
- Describe levels of organization in ecology.

Check Your Understanding

- What is adaptation?
- What is the scientific method?

Introduction

Organisms can be studied at many different levels, from biochemical and molecular, to cells, tissues and organs, to individuals, and finally at the ecological level: populations, communities, ecosystems and to the biosphere as a whole. Because of its focus on the higher levels of the organization of life on earth, ecology draws heavily on many other branches of science. Can you think of what some of these might be?

What is Ecology?

Ecology is the scientific study of how living organisms interact with each other and with their environment. Because of its broad scope, ecology draws from other branches of science, including geology, soil science, geography, meteorology, genetics, chemistry, and physics.

The study of ecology can also be broken down into sub-disciplines. Thus, if you were focusing on, for example, how the physiology of an organism influences the way that organism interacts with the environment, you would be studying the sub-discipline of ecophysiology. Similarly, you could come up with terminology for studying the roles of behavior, populations, communities, ecosystems, landscapes, evolution, and even politics!

You could also sub-divide ecology according to the species of interest into fields such as animal ecology, plant ecology, insect ecology, etc., or according to **biome**, an ecological formation that exists over a large region, such as the Arctic, the tropics, or the desert (**Figure** 23.1). Perhaps you can come up with some of your own terms for combining some of these specialties, or think of some other specialties yourself!

Figure 23.1: An example of a biome, the Atacama Desert, in Chile. (4)

Finally, because of the way ecologists study their discipline and because of the number of other fields involved, many methods can be employed to study how organisms interact with each other and their environment. Can you think of what some of these methods might be?

One obvious type of research that comes to mind is field studies, since ecologists generally are interested in the world of nature. This involves collecting data in the natural world, as opposed to laboratory settings with controls. One example of this kind of study is determining how many organisms occupy a specific geographical area. This usually involves a technique called sampling, where an area is divided into a certain sized plot, and the number of organisms in that area is counted.

Ecological principles can be studied in the laboratory as well. Perhaps you can think of some ways in which some aspects of ecology can be isolated in the lab. Statistical analysis is also used for analyzing both field and laboratory data. Finally, ecologists often use computer simulations to model complex ecological systems and to help predict how future environmental changes can affect a system. Can you think of some possible environmental change in the future that could be studied?

Organisms and Environments

All organisms have the abilities to grow and reproduce, properties which require materials and energy from the environment. The organism's environment includes physical properties (**abiotic** factors), such as sunlight, climate, soil, water and air, and biological properties (**biotic** factors), which are the other living organisms, both of the same and different species, which share its habitat. In other words, the biotic factors live in the same area. Biotic and abiotic factors will be further discussed in the Ecosystems lesson.

An example of how biotic factors influence the environment in which an organism lives can be seen in the primitive atmosphere. The first photosynthesizing organisms on Earth produced oxygen. This led to an oxygen-rich atmosphere, which caused life forms for which oxygen was toxic to die, and other organisms which needed oxygen to evolve.

Levels of Organization in Ecology

Ecology can be studied at a wide range of levels, from the smallest unit, at the individual level, to the largest, or most inclusive, the **biosphere** (the portion of the planet occupied by living matter (**Figure** 23.2)) (**Table** (23.1)). In between the individual level and the biosphere, from smallest to largest, are the **population** (organisms belonging to the same species that occupy the same area and interact with one another) level, the **community** (populations of different species that occupy the same area and interact with one another) level, and the **ecosystem** (a natural unit composed of all the living forms in an area, functioning together with all the abiotic components of the environment (**Figure** 23.3)) level.

Table 23.1: **Ecological Range**

Level	Definition
population	organisms belonging to the same species that occupy the same area and interact with one another
community	populations of different species that occupy the same area and interact with one another

Table 23.1: (continued)

Level	Definition
ecosystem	a natural unit composed of all the living forms in an area, functioning together with all the abiotic components of the environment
biosphere	the portion of the planet occupied by living matter

Ecologists study ecosystems at every level. They can ask different types of questions at each level. Examples of these questions are given in **Table** (23.2) , using zebras as an example.

Table 23.2: **Ecological Ecosystems**

Level	Question
Individual	How do zebras regulate internal water balance?
Population	What factors control zebra populations?
Community	How does a disturbance influence the number of mammal species in African grasslands?
Ecosystem	How does fire affect nutrient availability in grassland ecosystems?
Biosphere	What role does concentration of atmospheric carbon dioxide play in the regulation of global temperature?

Lesson Summary

- Ecology is the scientific study of how living organisms interact with each other and with their environment.
- The study of ecology can be broken down into subdisciplines and can be studied using various methods.
- The organism's environment includes abiotic and biotic factors.
- Levels of organization in ecology include the population, community, ecosystem and biosphere.

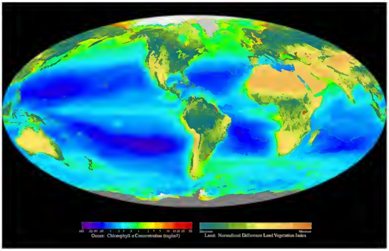

Figure 23.2: The "global biosphere," which includes all areas that contain life, from the sea to the atmosphere. (1)

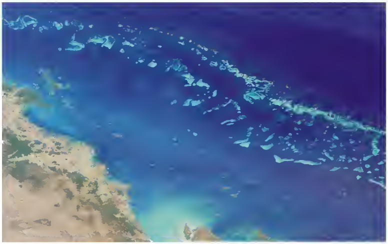

Figure 23.3: Satellite image of Australia's Great Barrier Reef, an example of a marine ecosystem (11)

Review Questions

1. What are three ways of sub-dividing the study of ecology? Give an example of each.
2. Name four types of research studies or methods that ecologists use.
3. Laboratory studies are valuable for studying ecological principles in that certain factors can be isolated and manipulated in a laboratory setting. Give an example of how the effect of an abiotic factor could be evaluated in the laboratory and the response of an organism measured.
4. A question that an ecologist could ask at the population level is "What factors control zebra populations?" Think of two examples in which another species might influence the zebra population.

Further Reading / Supplemental Links

- Unabridged Dictionary, Second Edition. Random House, New York, 1998.
- http://www.ecokids.ca/pub/index.cfm
- http://www.eco-pros.com/ecologykids.htm
- http://www.kidsolr.com/science/page12.html
- http://www.nceas.ucsb.edu/nceas-web/kids
- http://www.southplainfield.lib.nj.us/homeworklinks/Ecology.htm
- http://www.surfnetkids.com/ecology.htm;
- http://en.wikipedia.org/wiki

Vocabulary

abiotic Physical (nonliving) properties of an organism's environment, such as sunlight, climate, soil, water and air.

biome A homogeneous ecological formation that exists over a large region.

biosphere The portion of the planet occupied by living organisms.

biotic Biological (living) properties of an organism's environment, which are other living organisms which share its habitat.

community Populations of different species that occupy the same area and interact with one another.

ecology The scientific study of how living organisms interact with each other and with their environment.

ecosystem A natural unit composed of all the living forms in an area, functioning together with all the abiotic components of the environment.

population Organisms belonging to the same species that occupy the same area and interact with one another.

Points to Consider

- How do you think the study of ecology would be applied at the level of the population and what study methods do you think might be used?
- What do you think causes populations to grow?

23.2 Lesson 23.2: Populations

Lesson Objectives

- Explain what a population is.
- Describe how births, deaths and migration affect population size.
- Explain how populations grow.
- Describe how limiting factors affect population growth.
- Describe growth of the human population.

Check Your Understanding

- What is ecology?
- How does an organism interact with its environment?

Introduction

The study of populations is important to better understand the health and stability of a population. Such factors as births, deaths and migration influence population size. Different models explain how populations grow. Limiting factors can help determine how fast a population grows. All of these aspects of population biology can be applied to the study of human population growth.

What is a Population?

A **population** is comprised of organisms belonging to the same species, all living in the same area and interacting with each other. Since they live together in one area, members of the

same species form an interbreeding unit. Ecologists who study populations determine how healthy or stable they are and how they interact with the environment, by asking specific questions, such as, is a certain population stable, growing, or declining, and what factors affect the stability, growth, or decline of a threatened population?

In determining the health of a population, one must first measure its size or the **population density**, the number of individuals per unit area or volume, such as per acre. Population size or density can also be examined with respect to how individuals are distributed. How individuals are spaced within a population is referred to as **dispersion**. Some species may show a clumped or clustered distribution (**Figure** 23.4) within an area, others may show a uniform, or evenly spaced (**Figure** 23.5), distribution and still others may show a random, or unpredictable, distribution.

Figure 23.4: Individuals within this population of the purple loosestrife plant species show a clumped distribution due to local variation in soils. (20)

Other factors of importance in the study of populations are age and sex within the population. The proportion of males and females at each age level gives information about **birth rate** (number of births per individual within the population per unit time) and **death rate** (number of deaths per individual within the population per unit time), and this age structure may give further information about a population's health. For example, an age structure with most individuals below reproductive age often indicates a growing population. A stable population would have roughly equal proportions of the population at each age level, and a population with more individuals at or above reproductive age than young members describes a declining population.

Another pattern in populations has to do with how they change with time. Survivorship

Figure 23.5: A population of cacti in the Sonoran Desert generally shows uniform (even) dispersion due to competition for water. (10)

curves – graphing the population numbers over time - allow us to also study how populations grow and change, a topic that will be taken into more detail in subsequent lessons.

Births, Deaths, and Migration

Births, deaths and migration all affect population density and growth. The population growth rate is the rate at which the number of individuals in a population increases. Population growth rate depends on birth rate and on death rate. The growth rate then is represented by the equation:

growth rate = birth rate – death rate.

According to this equation, if the birth rate is greater than the death rate, then the population grows; if the death rate is greater, then the population declines. If the birth and death rates are equal, then the population remains stable.

Factors which influence a successful reproduction are age at first reproduction, frequency of reproduction, the number of offspring, parental care, reproductive lifespan, and death rate of offspring. In birds, **altricial** (helpless at birth and requiring much parental care (**Figure** 23.6)) and **precocial** (independent at birth or hatching and requiring little parental care (**Figure** 23.7)) strategies use different reproductive systems to ensure breeding success.

Migrations and other movements in and out of populations affect population density as well. Therefore, both birth and **immigration** (movement of individuals into a population from other areas) rates increase the population growth rate, while death and **emigration** (movement of individuals out of a population) rates decrease the population rate. The earlier growth rate equation now looks like this:

growth rate = (birth rate + immigration rate) – (death rate + emigration rate)

Figure 23.6: A hummingbird nest with young illustrates an altricial reproductive strategy, with a few, small eggs, helpless and naked young, and intensive parental care. (18)

Figure 23.7: Canada Goose, *Branta Canadensis*, adult and young show a precocial reproductive strategy, where they lay a large number of large eggs, producing well-developed young. (13)

One type of migration that you are probably pretty familiar with is the direct, often seasonal, movement of a species that results in a predictable change for that population size. Maybe you've heard that 'birds fly south for the winter." Examples of this migration are the thousands-of-miles migrations that many birds perform in the fall and then again in the spring when they return to their original habitat (**Figure** 23.8). Another example of a long-distance migration is the movements of Monarch butterflies from their Mexican wintering grounds to the northern summer habitats (in various regions of the United States) and back again. These types of migrations move entire populations from one set of location and environmental conditions to another.

Figure 23.8: A flock of barnacle geese, *Branta leucopsis*, fly in formation during the autumn migration in Finland. (26)

Population Growth

Under ideal conditions, given unlimited amounts of food, moisture, and oxygen, and suitable temperature and other environmental factors, oxygen-consuming organisms show exponential or geometric growth, where as the population grows larger, the growth rate increases. This is shown as the "J-shaped curve" in **Figure** 23.9. You can see that the population grows slowly at first, but as time passes, growth occurs more and more rapidly.

These ideal conditions are not often found in nature. They occur sometimes when populations move into new or unfilled areas. If ideal conditions were found all the time, what would you expect to happen to populations?

In nature, limits occur. One basic requirement for life is energy; growth, survival and reproduction all require this. Do you think energy supplies are limited or unlimited?

The answer is they are limited and therefore organisms must use these resources and others wisely. How do you think this affects the way organisms grow and what do you think the growth rate would look like?

In nature, under more realistic conditions, at first populations grow exponentially (J-shaped curve), but as populations increase, rates of growth slow and eventually level off. This is

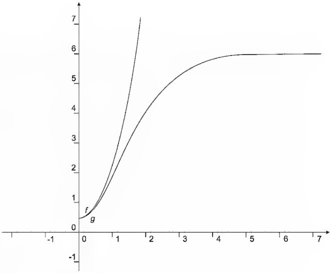

Figure 23.9: Growth of populations according to Malthus' exponential (or J-curve) growth model (left) and Verhulst's logistic (or S-curve) growth model (right) (14)

shown as an "S-shaped curve" in **Figure** 23.9. Why do you think this is? You would be right if you said because various factors limit the growth of populations. Can you think of which factors these could be?

Limiting Factors

Limiting factors that can lower the population growth rate include reduced food supply and reduced space. These can have the effect of lowering birth rates, increasing death rates, or can lead to emigration. This growth model is known as the logistic (S-curve) model, and looks different than the one for exponential growth (**Figure** 23.9). In this case, the growth rate begins as proportional to the size of the population, but at higher population levels, competition for limited resources leads to lower growth rates. Eventually, the growth rate stops increasing and the population becomes stable.

This plateau in growth is known as the **carrying capacity**, or the maximum population size that can be supported in a particular area without degradation of the habitat. Limiting factors determine what the carrying capacity is.

In general, a limiting factor is a living or nonliving property of a population's environment, which regulates population growth. There are two different types of limiting factors: **density-dependent factors and density-independent factors.**

Density-dependent factors, such as food supply, promote competition between members of the same population for the same resource, as the population increases in size and there is more crowding. Therefore, the population size is limited by such factors.

In the example of food supply, when population size is small, there is plenty of food for each individual and birth rates are high. As the population increases, the food supply decreases and birth rates decline, causing the population growth rate to decrease. Food shortages can eventually lead to an increase in death rates or emigration, therefore leading to a negative growth rate and lower population size. With a lower population size, each individual has more food and the population begins to increase again, reaching the carrying capacity. Can you think of some other density-dependent limiting factors?

Such factors could include light, water, nutrients or minerals, oxygen, the ability of an ecosystem to recycle nutrients and/or waste, disease and/or parasites, temperature, space, and predation. Can you think of some other factors that limit populations, but seldom regulate them? That means that these factors act irregularly, regardless of how dense the population is. Populations limited by such factors seldom reach carrying capacity.

An example of this other kind of factor, a density-independent factor, is weather. For example, an individual agave (century plant) has a lifespan dependent at least in part by erratic rainfall. Rainfall limits reproduction, and which in turn limits growth rate, but because of rainfall's unpredictability, it cannot regulate Agave populations. Can you think of some other factors like this?

Human activities, for example, act in this way. These include use of pesticides, such as DDT, and herbicides, and habitat destruction. See if you can come up with explanations as to why these factors are considered density-independent factors.

We will next be examining the growth of human populations. What kind of growth rate do you think humans follow?

Growth of the Human Population

There are two major schools of thought about human population growth. One group of people, sometimes known as the "Neo-Malthusians," believes that human population growth cannot continue without dire consequences. Another group, the "Cornucopians," believes that the Earth can provide an almost limitless amount of natural resources and that technology can solve or overcome low levels of resources and degradation of the environment caused by the increasing population. Which do you think is correct?

If we look back again at the growth curves that we examined in the last two sections, we might ask ourselves if human growth resembles the exponential J-shaped model or the logistic S-shaped model? In other words, are we built, as a population, to keep growing and to use up all our resources, and thus become extinct, or will we efficiently use our resources so that the Earth can sustain our growth?

We don't know all the answers yet, but by looking at population growth through history and by examining population growth in different countries we may see some patterns emerge. For example, if we look at worldwide human population growth from 10,000 BCE through today, our growth, overall, resembles exponential growth, increasing very slowly at first, but later growing at an accelerating rate and which does not approach the carrying capacity (**Figure** 23.10).

However, by looking at different countries' population growth over history, we see more complexity. The history of human population growth can be divided into four stages and we can see snapshot views of these stages in countries today. Human populations pass through these four or five predictable stages of growth (**Table** 23.3):

Table 23.3: **The Stages of Human Population Growth**

Stage of Human Population Growth	Description
Stage 1	Birth and death rates are high and population growth is stable (i.e. early human history)
Stage 2	Significant drop in death rate, resulting in an increasingly rapid rise in population size (exponential growth)(i.e. 18th and 19th century Europe)
Stage 3	Population size continues to grow
Stage 4	Birth rates equal death rates and populations become stable
Stage 5	Total population size may level off

In looking ahead to the future, projections by the United Nations and the US Census Bureau predict that by 2050, the Earth will be populated by 9.4 billion people. Other estimates predict 10 to 11 billion. The Cornucopians believe that more people are good for technology and innovation. The 5-stage model above predicts that when all countries are industrialized, the human population will eventually reach stability and a carrying capacity of sorts. However, many scientists and other Neo-Malthusians believe that humans have already gone over the Earth's carrying capacity for resources and habitat, and that this will eventually lead to famine, epidemics, or war, thus causing a population crash or even extinction.

Which of the above theories makes sense to you? What ways can you think of that people might use to avoid reaching Earth's carrying capacity?

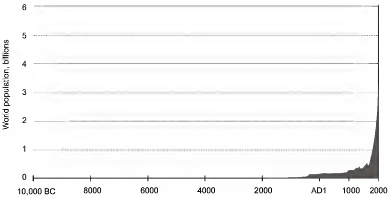

Figure 23.10: Worldwide human population growth from 10,000 BCE through today (9)

Lesson Summary

- A population is comprised of organisms belonging to the same species, all living in the same area and interacting with each other
- One measure of a population's health is the dispersion of individuals within a population
- Information about birth rate, death rate, and survivorship curves also show how populations grow and change
- The population growth rate shows how the population size changes per population member per unit of time and depends on birth and death rates and migration
- There are different types of migrations that affect population density
- Under ideal conditions, populations show exponential growth; under more realistic conditions, limiting factors (density-dependent and density-independent factors) cause logistic growth
- There are two major schools of thought about human population growth; the Neo-Malthusians and the cornucopians

Review Questions

1. Name two ways in which ecologists can get an idea of the health of a population.
2. For a secretive or highly mobile species, how might you determine population size?
3. What might cause a clumped or clustered dispersion?
4. In an altricial reproductive strategy used by robins and hummingbirds, the birds hatch helpless and naked. Parents invest little energy in just a few, small eggs. It is important these offspring survive, because there are so few. What strategies might parents use to ensure that their young survive?
5. How does a limiting factor such as food supply limit population size?
6. In human history, major advances in technology caused an increase in carrying capacity.

What do you think these major advances were?

7. Name some environmental crises that support the idea that our human population has already grown beyond the carrying capacity resulting in environmental degradation.

Further Reading / Supplemental Links

- http://www.brainpop.com/science/ourfragileenvironment/populationgrowth/preview.weml
- http://eelink.net/pages/EE+Activities+-+Population
- http://mathforum.org/t2t/faq/census.html
- http://en.wikipedia.org/wiki/Population_ecology

Vocabulary

altricial Newborn that are helpless at birth and require much parental care.

birth rate Number of births per individual within the population per unit time.

carrying capacity Maximum population size that can be supported in a particular area without degradation of the habitat.

death rate Number of deaths per individual within the population per unit time.

density-dependent factors Promote competition between members of the same population for the same resource; food and space are examples.

density-independent factors Act irregularly, regardless of how dense the population is; temperature and climate are examples.

dispersion Spacing of individuals within a population.

emigration Movement of individuals out of a population.

immigration Movement of individuals into a population from other areas.

limiting factor A living or nonliving property of a population's environment, which regulates population growth.

population growth rate How the population size changes per population member per unit of time.

precocial Newborn that are independent at birth or hatching and require little parental care.

Points to Consider

- Now that you understand what makes up a population, what do you think makes up a community?
- You have learned about some of the factors that limit populations. What do you think are some interactions that affect the community?

23.3 Lesson 23.3: Communities

Lesson Objectives

- Explain what a community is.
- Describe community interactions
- Explain what competition is and how it affects the community.
- Describe predation and how that affects prey density.
- Explain what symbiosis is and give examples of different kinds of symbiosis.

Check Your Understanding

- What is a population?
- How do density-dependent factors promote competition between members of the same population?

Introduction

Now that we have examined the dynamics of a single species at the population level, we are now ready to move to the next higher level. This is the community level, where we look at how populations of different species that occupy the same area interact with each other. As we will see, there are a number of types of interactions, including competition, predation and symbiosis. These interactions in turn affect the species' interactions with one another.

What is a Community?

A **community** is an assemblage within the same area, of populations of different species interacting with one another. The term can be used in various ways with differences in meaning. For example, it may be limited to specific places, at specific times, or certain types of organisms. Thus, one may study the fish community in Lake Ontario or the fish in this lake during a specific period, such as the period before industrialization.

A community may also be defined according to the classification of and the geographic distribution of species, as in an oak-hickory forest. On the other hand, a community might be defined according to function and behavior, as in a forest that is moderate in temperature (temperate) and sheds leaves annually (deciduous).

Community Interactions

Community interactions can be either intraspecific, that is between members of the same species, or interspecific, between members of different species. There are a number of different types of interactions, such as competition, predation, and symbiosis, which can be described as beneficial, detrimental or neutral. For example, competition could be looked at as having negative effects on the competing individuals or species, whereas mutualism, a type of symbiosis, could be determined as positive for individuals involved.

As we examine different types of interactions in the next few sections, we will see more specifically why interactions are considered positive, negative, or neutral. We usually look at costs and benefits in terms of fitness, or survival and reproduction. These types of interactions may alter populations, communities, and even ecosystems, and the evolution of interacting species.

Competition

Competition can be defined as an interaction between organisms of the same or different species, in which the "fitness" of one is lowered by the presence of another. Individuals compete for a limited supply of at least one resource, such as food, water, or territory. Fitness refers to the ability of a species to survive and reproduce.

Competition can be described in terms of the mechanisms by which it occurs, either directly or indirectly. For example, competition may occur directly between individuals via aggression or some other means, whereby individuals interfere with survival, foraging or reproduction, or by physically preventing them from occupying an area of the habitat. Indirect competition is when a common limiting resource which acts as an intermediate. For example, use of a specific resource or resources decreases the amount available to others, thereby affecting the others' fitness, or competition for space results in negatively affecting the fitness of one of the competing individuals.

Another type of indirect competition also occurs when two species are both preyed upon by the same predator. If the population size of one species increases, this would cause the predator population to increase, and would result in the other species' population size decreasing.

Intraspecific competition occurs when members of the same species compete for the same resources, like food, nutrients, space, or light. Two organisms competing for the same re-

source can adapt to such conditions. Thus, if two trees growing close together are competing for light, water, and nutrients, one may out-compete the other by growing taller to get more available light or be developing a larger root system to get more water and nutrients. Such a situation results in survival for the organism that has better adapted to that environment.

Interspecific competition occurs when individuals of different species share a limiting resource in the same area, resulting in one of the species having lowered reproductive success, growth, or survival. For example, cheetahs and lions feed on similar prey. If prey is limited, then one species may catch more prey than the other and force the other species to either leave the area or to directly affect its survival. Lions sometimes steal prey killed by cheetahs. This could negatively affect the survival of the cheetahs.

According to the **competitive exclusion principle**, species less suited to compete for resources will either adapt, be excluded from the area, or die out. This is similar to what happens within a species. Evolutionary theory says that competition for resources within and between species plays an important role in natural selection (**Table** (23.4)).

In order for two species within the same area to adapt, they may develop different specializations in order to coexist. This is known as **character displacement** and an example of this is the different feeding adaptations, such as bill structure, that developed in Darwin's Finches (**Figure** 23.11).

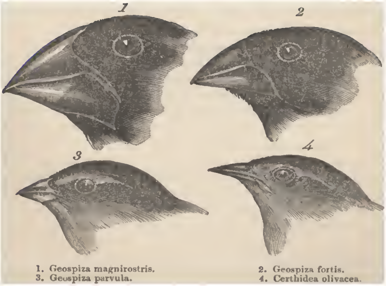

Figure 23.11: An example of character displacement, showing different bill structures, reflecting different feeding strategies, in Darwin's or Galapagos Finches. From Darwin's Journal, 1845, during the voyage of the H.M.S. Beagle. (17)

Table 23.4: **Main Features of Competition**

Type of Competition	Description of Competition
Direct Competition	Occurs directly between individuals via aggression or some other means
Indirect Competition	Occurs indirectly through a common limiting resource, which acts as an intermediate, and/or occurs between two species which are both preyed upon by the same predator
Intraspecific Competition	Occurs when members of the same species compete for the same resources, like food, nutrients, space, or light
Interspecific Competition	Occurs when individuals of different species share a limiting resource in the same area

Predation

Predation is an interaction where a predator organism feeds on another living organism or organisms, known as prey. Predators may or may not kill their prey prior to eating them. The key characteristic of predation is the direct effect of the predator on the prey population.

In all classifications of predation, the predator lowers the prey's fitness, by reducing the prey's survival, reproduction, or both. Other types of consumption, like detritivory, where dead organic material (detritus) is consumed, have no direct impact on the population of the food item.

Predation can be classified in a number of different ways. One way is to classify it functionally, by the extent to which they feed on and interact with their prey. This type includes true predation, grazing, and parasitism. (Parasitism will be discussed later in this lesson.)

True predation is a type in which the predator kills and eats its prey. Some predators of this type, such as jaguars, kill large prey and dismember or chew it prior to eating it (**Figure** 23.12). Others, such as a bottlenose dolphin or snake, may eat its prey whole. In some cases, the prey dies in the mouth or digestive system of the predator. Baleen whales, for example, eat millions of plankton at once, with the prey being digested afterward. Predators of this type may hunt actively for prey, or sit and wait for prey to approach within striking distance.

In **grazing**, the predator eats part of the prey, but rarely kills it. Many of this type of prey species are able to regenerate or regrow the grazed parts, so there is no real effect on the population. For example, most plants can regrow after being grazed upon by livestock. Kelp regrows continuously at the base of the blade to cope with browsing pressure. Starfish, also, can regenerate lost arms when they are grazed on. Parasites feed in a similar way to grazers,

Figure 23.12: An example of a true predator, showing a lioness actively hunting warthogs in the western corridor of the Serengeti, in Africa. (2)

but are noted for their close association with their host species, and will be discussed further in the next section on symbiosis.

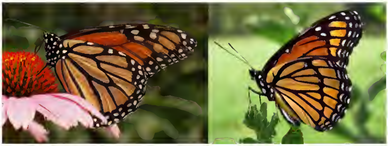

Figure 23.13: An example of Batesian mimicry, where the Viceroy butterfly (*Limenitis archippus*) (right) mimics the unpalatable Monarch butterfly (*Danaus complexions*) (left). Both species are avoided by predators to a greater degree than either one would be otherwise. (23)

Another way of classifying predators is by degree of specialization. Many predators, such as pandas and the snail kite, specialize in hunting only one species of prey, or certain classes of prey. Others, such as humans, leopards, and dogs, will kill and eat a wide variety of species. Specialists are usually well adapted in capturing their prey, but prey may be equally well adapted in escaping the predator. This helps to keep both populations in equilibrium. Almost all specialists will usually successfully switch to other prey or may resort to scavenging or even a vegetarian diet, if the preferred prey is extremely scarce.

Predators play an ecological role, in that they may increase the biodiversity of communi-

ties by preventing a single species from becoming dominant, as in grazers of a grassland. Introduction or removal of these dominant **keystone species**, or changes in its population density, can have drastic effects on the equilibrium of many other populations in the ecosystem.

The act of predation can be broken down into four stages: detection of prey, attack, capture, and consumption. At each stage, predator and prey have adaptations for obtaining food and avoiding predation (**Table** (23.5), respectively. One mechanism to avoid detection is **camouflage** (**Figure** 23.14), where species have an appearance (color, shape or pattern) which helps them blend into the background. Mimicry is a related phenomenon where a species uses appearance to copy another species, and which is used by both predators and prey (**Figure** 23.13).

Table 23.5: **Main Features of Predation**

Type of Predation	Description of Predation
True Predation	Predator kills and eats its prey
Grazing	Predator eats part of the prey, but rarely kills it
By degree of Specialization	Predator specializes in hunting only one species of prey, or certain classes of prey, or predator kills and eats a wide variety of prey species

Other anti-predator adaptations involve mobbing behavior, where a prey species cooperatively attacks or harasses a predator, as in crows and smaller birds working together to drive away a hawk. Prey may also suggest is is unprofitable to chase, as in the case of a Thomson's gazelle stotting (jumping into the air with the legs kept straight and stiff, and with a visible white rear) to let predators know not to give chase. This is known as advertisement of unprofitability.

Anti-predatory Adaptations

Camouflage Species have an appearance which helps them blend into background

Mimicry Species uses appearance to copy another species, and is used by both predators and prey

Mobbing Behavior A prey species cooperatively attacks or harasses a predator

Advertisement of Unprofitability Prey species advertises in order to let predator know not to give chase

Figure 23.14: Camouflage by the dead leaf mantis, *Deroplatys desiccaa*, makes it less visible to both its predators and prey. If alarmed, it lies motionless on the rainforest floor of Madagascar, Africa, camouflaged among the actual dead leaves. It eats other animals up to the size of small lizards. (19)

Symbiosis

The term **symbiosis** commonly describes close and often long-term interactions between different species, in which at least one species benefits. The symbiotic relationship may be characterized as being mutualistic, commensalistic, or parasitic. In **mutualism**, both species benefit; in **commensalism**, one species benefits while the other is not affected; and in **parasitism**, the parasitic species benefits, while the host species is harmed.

Symbiotic Relationships

Mutualism Both species benefit.
Commensalism One species benefits, while the other is not affected.
Parasitism Parasitic species benefits, while host species is harmed.

Mutualistic relationships include the large percentage of herbivores that have gut fauna that help them digest plant matter, coral reefs that have various types of algae living inside, and the relationship between the Ocellaris clownfish and the Ritteri sea anemones. In the latter example, the clownfish protects the anemone from anemone-eating fish, and in turn, the stinging tentacles of the anemone protect the clownfish from its predators (**Figure** 23.15).

Commensal relationships may involve an organism using another for transportation or housing, such as spiders building their webs on trees, or may involve an organism using something another created, after the death of the first.

Parasites include those that either live within the host's body, such as hookworms, or those that live on its surface, such as lice. In addition, parasites may either kill the host they live on, or rely on the host surviving. Parasites are found not only in animals but also in plants and fungi.

Figure 23.15: A mutualistic relationship between the Ocellaris clownfish and the Ritteri sea anemone. Myako Island, Japan. The fish protects the anemone from anemone-eating fish and the anemone protects the clownfish from its predators, with its stinging tentacles. The clownfish has a special mucus which protects it from the tentacles. (22)

Lesson Summary

- A community is an assemblage within the same area, of populations of different species interacting with one another.
- Community interactions include competition, predation, and symbiosis.
- Competition can be either direct or indirect.
- Intra- and inter-specific competition occur when individuals share a limiting resource in the same area.
- The competitive exclusion principle plays an important role in natural selection.
- Functional types of predation include true predation, grazing, and parasitism.
- Predators can also be classified by degree of specialization.
- Prey use different adaptations to avoid detection, attack and capture by predators.
- Symbiosis includes mutualism, commensalism, and parasitism.

Review Questions

1. Define competition.
2. If the geographic distributions of two similar species do not overlap, would you expect the two species to have character displacement? Why or why not?
3. Observations of natural populations and manipulative experiments show that two recently evolved species of threespine stickleback fish (*Gasterosteus* spp.) show two distinct morphologies and feeding strategies in order to co-exist in the post-glacial lakes in which they live in western Canada. Morphologically they differ in the size, shape and the number and length of gill rakers, structures used in their feeding. Name two ways in which these fish species could use different feeding strategies in order to co-exist.
4. How might a predator lower a prey's fitness?
5. In most types of grazing, does the predator lower a prey's fitness? Why or why not?
6. A drone fly looks a lot like a bee, yet it is completely harmless as it cannot sting at all. What anti-predator mechanism is the drone fly using? Would you expect predators to always avoid drone flies?
7. In the mutualistic relationship between the Ocellaris clownfish and the Ritteri sea anemones, what benefit does the fish get?
8. Hosts may evolve defenses against their parasites. In turn, parasites evolve in response to these defense mechanisms, including evolving adaptations that are specific to a particular host taxon, even specializing to the point where they infect only a single species. How might such narrow host specificity be costly over evolutionary time? What would help to reduce this cost?

Further Reading / Supplemental Links

en.wikipedia.org/wiki/Symbiosis

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- http://www.nclark.net/CommunitiesBiomes
- http://www.ecokidsonline.com/pub/index.cfm

Vocabulary

camouflage When species have an appearance which helps them blend into the background.

character displacement Two or more species within the same area develop different specializations in order to coexist.

commensalism A type of symbiosis in which one species benefits while the other is not affected.

community An assemblage within the same area, of populations of different species interacting with one another.

competition Organisms of the same or different species compete for a limited supply of at least one resource, thereby lowering the fitness of one organism by the presence of the other.

competitive exclusion principle Species less suited to compete for resources will either adapt, be excluded from the area, or die out.

grazing A type of predation where the predator eats part of the prey, but rarely kills it.

keystone species A predator species that plays an important role in the community by controlling the prey population and, thus, the populations of other species in the community as well.

mutualism A type of symbiosis in which both species benefit.

parasitism A type of symbiosis in which the parasite species benefits, while the host species is harmed.

predation An interaction where a predator organism feeds on another living organism or organisms, known as prey.

symbiosis Close and often long-term interactions between different species, in which at least one species benefits.

true predation A type of predation where the predator kills and eats the prey.

Points to Consider

- How do you think predation helps a species to survive?

23.4 Lesson 23.4:: Ecosystems

Lesson Objectives

- Explain what an ecosystem is.
- Discuss how biotic and abiotic factors play a role in the ecosystem.
- Explain what a niche is and its importance in an ecosystem.
- Describe what a habitat is and how an organism is adapted to live in the habitat.

Check Your Understanding

- What is a community?
- What are the different types of community interactions?

Introduction

Now that you have studied what a community is, you have seen some of the interactions that occur between species. The next level, the ecosystem, includes not only the biological components, but also the abiotic components, all functioning together. You will examine in more depth biotic and abiotic factors, and how the concepts of the niche and habitat play important roles in the ecosystem.

What is an Ecosystem?

An **ecosystem** is a natural unit consisting of all the biotic factors (plants, animals and micro-organisms) functioning together in an area along with all of the abiotic factors (the non-living physical factors of the environment). The concept of an ecosystem can apply to a large body of freshwater, for example, as well as a small piece of dead wood. Other examples of ecosystems include the coral reef, the Greater Yellowstone ecosystem, the rainforest, the savanna, the tundra, the desert and the urban ecosystem (**Figure** 23.16).

Ecosystems, like most natural systems, depend on continuous inputs of energy from outside the system, most in the form of sunlight. In addition to energy being transferred within the ecosystem, matter is recycled in ecosystems. Thus, elements such as carbon and nitrogen, and water, all needed by living organisms, are used over and over again. These topics will be discussed in more detail in the *Ecosystem Dynamics* chapter.

Ecosystems can be discussed with respect to humans as well. A system as small as a household, neighborhood, or college, or as large as a nation, may then be suitably discussed as a human ecosystem. While they may be bounded and individually discussed, human ecosystems do not exist independently, but interact in a web of complex human and ecological

Figure 23.16: An example of a desert ecosystem, a desert in Baja California, showing Saguaro cactus. (15)

relationships connecting all human ecosystems.

Since humans touch virtually all surfaces of the earth today, all ecosystems can be more accurately considered as human ecosystems. In 2005, the largest assessment ever conducted of the earth's ecosystems was done by a research team of over 1,000 scientists. The study concluded that in the past 50 years, humans have altered the earth's ecosystems more than any other time in our history.

Biotic and Abiotic Factors

Biotic factors of an ecosystem include all living components, from bacteria and fungi, to unicellular and multicellular plants, to unicellular and multicellular animals. **Abiotic factors** are non-living chemical and physical factors in the environment. The six major abiotic factors are water, sunlight, oxygen, temperature, soil and climate (such as humidity, atmosphere, and wind). Other factors which might also come into play are other atmospheric gases, such as carbon dioxide, and factors such as physical geography and geology.

Abiotic and biotic factors not only interrelate within an ecosystem but also between ecosystems. For example, water may circulate between ecosystems, by the means of a river or ocean current, and some species, such as salmon or freshwater eels, move between marine and freshwater systems. This concept will be explained more fully in the Biomes and the Biosphere lesson.

Niche

One of the most important ideas associated with ecosystems is the **niche** concept. A niche refers to the role a species or population plays in the ecosystem, with respect to all the interactions with the abiotic and biotic components of the ecosystem. A shorthand definition is that a niche is how an organism "makes a living". Some of the important aspects of a species' niche are the food it eats, how it obtains the food, nutrient requirements, space, etc.

The different dimensions of a niche represent different biotic and abiotic variables. These factors may include descriptions of the organism's life history, habitat, trophic position (place in the food chain), and geographic range.

Different species can hold similar niches in different locations, and the same species may occupy different niches in different locations. Species of the Australian grasslands, although different from those of the Great Plains grasslands, occupy the same niche.

Once a niche is left vacant, other organisms can fill in that position. When the tarpan (a small, wild horse, chiefly of southern Russia) became extinct in the early 1900s, the niche it left vacant has been filled by other animals, in particular a small horse breed, the konik (**Figure** 23.17).

Figure 23.17: The konik horse, which filled the niche left vacant by the tarpan, a horse that became extinct in the early 1900s in southern Russia. (16)

When plants and animals are introduced, either intentionally or by accident, into a new environment, they can occupy the new niches or niches of native organisms, and sometimes outcompete the native species, and become a serious pest. For example, kudzu, a Japanese vine, was introduced intentionally to the southeastern United States in the 1870s to help

control soil erosion. Kudzu had no natural enemies there and was able to outcompete native species of vines and take over their niches (**Figure** 23.18).

Figure 23.18: Kudzu, a Japanese vine, introduced intentionally to the southeastern United States, has outcompeted the native vegetation. (8)

As already discussed in the Communities lesson, the competitive exclusion principle states, that if niche overlap occurs, either one species will be excluded, character displacement will occur (as in Darwin's Finches), or extinction occurs.

Habitat

The **habitat** is the ecological or environmental area where a particular species lives; the physical environment to which it has become adapted and in which it can survive (**Figure** 23.19). A habitat is generally described in terms of abiotic factors, such as the average amount of sunlight received each day, the range of annual temperatures, and average yearly rainfall. These and other factors determine the kind of traits an organism must have in order to survive there (**Figures** 23.20 and 23.21).

Habitat destruction is a major factor in causing a species population to decrease, eventually leading to it being endangered or even going extinct. Large scale land clearing usually results in the removal of native vegetation and habitat destruction. Poor fire management, pest and weed invasion, and storm damage can also destroy habitat. National parks, nature reserves, and other protected areas all provide adequate refuge to organisms by preserving habitats. The *Environmental Problems* chapter will discuss habitat destruction in further detail.

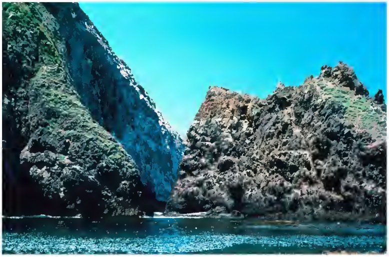

Figure 23.19: Santa Cruz, the largest of the northern Channel Islands, has the most diverse of habitats in the sanctuary, including a coastline with steep cliffs, coves, gigantic caves, and sandy beaches. (5)

Figure 23.20: Another example of a type of habitat, showing a meadow and representative vegetation. (3)

Figure 23.21: Winter flock of bearded reedling in their natural habitat of dense wetland reeds, in Helsinki, Finland (6)

Habitats can also be examined from a human point of view. Thus, it is the environment in which humans live, work, recreate, and move about. Human habitat is the sum total of all factors which constitute the total environment where humans live, work, and perform their essential and day-to-day obligations.

Lesson Summary

- An ecosystem is a natural unit consisting of all the biotic and abiotic factors functioning together in an area.
- Biotic factors include all living components of an ecosystem and abiotic factors are the non-living chemical and physical factors in the environment.
- There are six major abiotic factors.
- The niche concept is one of the most important ideas associated with ecosystems.
- If niche overlap occurs, then the competitive exclusion principle comes into play.
- The habitat is the area where a particular species, species population, or community lives.
- Habitat destruction is a major cause of population decrease, leading to possible extinction.
- Both the ecosystem and habitat can be looked at from a human point of view.

Review Questions

1. Give three examples of ecosystems.

2. List three abiotic components of importance to trees living in a forest.
3. Give an example of an organism filling a vacant niche.
4. Why might an introduced species become a pest?
5. How could separation of breeding periods in frogs result in niche differentiation in the tadpoles?
6. Name three abiotic factors that a habitat is generally described in terms of.
7. Species which travel distances between important areas for their survival, such as breeding and feeding areas may be particularly vulnerable to habitat destruction. How might the creation of multiple national parks or nature reserves help such species?

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Vocabulary

abiotic factors All the non-living chemical and physical factors in the environment.

biotic factors All the living components of an ecosystem.

ecosystem A natural unit consisting of all the biotic factors functioning together in an area along with all of the abiotic factors.

habitat Ecological or environmental area where a particular species live.

niche A specific role that an organism occupies within an ecosystem.

Points to Consider

- Now that you understand what makes up an ecosystem, what additional factors do you think might be added to get to the next level, the biome?
- How do you think what you have learned about abiotic and biotic factors might be applied to the classification of different biomes?

- The biosphere is considered to be a global ecological system. Given all you now know about ecology, what do you think the biosphere consists of?

23.5 Lesson 23.5: Biomes and the Biosphere

Lesson Objectives

- Explain what biomes are.
- Describe terrestrial biomes.
- Describe aquatic biomes.
- Describe the features of the biosphere and list specific systems.

Check Your Understanding

- What is an Ecosystem?
- How can Ecosystems be discussed with respect to Humans?

Introduction

The concept of biomes and the largest biome of all, the biosphere, is the highest level of organization in ecology, building on everything you have already studied at the population, community, and ecosystem levels. There is a wide variety of biomes, classified into two major groups, terrestrial and aquatic biomes. Because the biosphere integrates all living beings, and can be considered itself a kind of living organism, human activities on one part of Earth can have a major effect on another. In order to better understand all the interactions on Earth, scientists have created various small-scale models.

What are Biomes?

A **biome** is a climatically and geographically defined area of ecologically similar communities of plants and animals, often referred to as ecosystems. Biomes are often identified with particular patterns of ecological succession and climax vegetation (See the *Ecosystem Dynamics* chapter).

Biome type may also be based on differences of the physical environment (for example, mountain ranges or oceans). Their variation is generally related to the distribution of species according to their ability to tolerate temperature and/or dryness. For example, one may find photosynthetic algae only in the part of the ocean where light penetrates, while conifers are mostly found in mountains.

The biodiversity characteristic of each biome, especially the diversity of fauna and subdominant plant forms, is a function of abiotic factors and the biomass productivity of the dominant vegetation. Species diversity tends to be higher in terrestrial biomes with higher net primary productivity, moisture availability, and temperature. Biodiversity also generally increases most rapidly near the equator and less rapidly toward the poles, and increases with humidity.

The most widely used systems of classifying biomes correspond to latitude (or temperature zoning) and humidity. One scheme, developed by the World Wildlife Fund (WWF), identified fourteen biomes, called major habitat types, and further divided the world's land area into 825 terrestrial ecoregions. This classification is used to define the Global 200 list of ecoregions identified by the WWF as priorities for conservation. Some of these habitat types are similar to others already discussed, while others include mangroves, flooded grasslands, and savannas.

Biomes are often given local names. For example, a temperate grassland or shrubland biome is known as steppe in central Asia, prairie in North America, and pampas in South America. Tropical grasslands are known as savanna or veldt in southern Africa and outback or scrub in Australia.

Terrestrial Biomes

Terrestrial biomes are defined based on factors such as plant structures (such as trees, shrubs, and grasses), leaf types (such as broadleaf and needleleaf), and plant spacing (forest, woodland, savanna). Climate is also a major factor determining the distribution of terrestrial biomes. Among the important climatic factors are latitude, from the poles towards the equator (Arctic, boreal, temperate, subtropical, tropical); humidity (humid, semi-humid, semi-arid, and arid), with seasonal variation in rainfall; and elevation (increasing elevation causes a distribution of habitat types similar to that of increasing latitude) (**Table** (23.6)). Terrestrial biomes (**Figure** 23.22) lying within the Arctic and Antarctic Circles are relatively barren of plant and animal life, while most of the more populous biomes lie near the equator (**Figure** 23.23).

Table 23.6:

Characteristics of Terrestrial Biome	Description of Characteristics
Plant structures	Trees, shrubs, grasses
Leaf types	Broadleaf, needleleaf
Plant spacing	Forest, woodland, savanna
Latitude from poles towards the equator	Arctic, boreal, temperate, subtropical, tropical
Humidity	Humid, semi-humid, semi-arid, arid

Table 23.6: (continued)

Characteristics of Terrestrial Biome	Description of Characteristics
Elevation	Increasing elevation causes habitat types similar to that of increasing latitude

Aquatic Biomes

Aquatic biomes (which also can be classified into freshwater and marine biomes) can be defined according to:

- size
- depth, such as the continental shelf
- vegetation, such as a kelp forest
- animal communities
- other physical characteristics, including pack ice or hydrothermal vents

According to the WWF scheme, freshwater biomes can be classified according to:

- large lakes
- large river deltas
- polar freshwaters
- montane freshwaters (in mountain areas)
- temperate coastal rivers
- temperate floodplain rivers and wetlands
- temperate upland rivers
- tropical and subtropical coastal rivers
- tropical and subtropical floodplain rivers and wetlands
- tropical and subtropical upland rivers
- xeric (dry habitat) freshwaters and endorheic (interior drainage) basins
- oceanic islands

The WWF classifies marine biomes according to:

- polar habitat types
- temperate shelves and seas
- temperate upwelling
- tropical upwelling
- tropical coral

Figure 23.22: One of the terrestrial biomes, a taiga, a coniferous evergreen forest of the subarctic, covering extensive areas of northern North America and Eurasia. This taiga is along the Denali Highway in Alaska. The Alaska Range is in the background. (12)

Figure 23.23: A terrestrial biome, a tropical rainforest, located in the Amazon basin north of Manaus, Brazil. The image was taken within 30 minutes of a rain event, and a few white 'clouds' above the canopy are indicative of rapid evaporation from wet leaves after the rain. (25)

Other marine habitat types include:

- continental shelf
- littoral/intertidal zone
- coral reef
- kelp forest (**Figure** 23.24)
- pack ice (**Figure** 23.25)
- hydrothermal vents
- cold seeps
- benthic zone
- pelagic zone
- neritic zone

Figure 23.24: An example of an aquatic marine biome, a kelp forest, located near Santa Cruz Island, Channel Islands. National Park, California. (7)

The Biosphere

The most inclusive level of organization in ecology is the **biosphere**. It is the part of the Earth, including air, land, surface rocks, and water, within which life occurs, and which biotic processes in turn alter or change. It is the global ecological system integrating all life forms and their relationships, including their interactions with the outer layer of the earth: the lithosphere (or sphere of soils and rocks), hydrosphere (or sphere of water) and atmosphere (or sphere of the air). The biosphere occurs in a very thin layer of the planet, extending from about 11,000 meters below sea level to 15,000 meters above sea level and reaches well into the other three spheres.

Figure 23.25: An example of an aquatic marine biome, pack ice. (24)

The concept that the biosphere is itself a living organism, either actually or metaphorically, is known as the **GAIA hypothesis**. The hypothesis explains how biotic and abiotic factors interact in the biosphere. It considers Earth itself a kind of living organism. Its atmosphere, heliosphere, and hydrosphere are cooperating systems that yield a biosphere full of life. Lynn Margulis, a microbiologist, added to the hypothesis, specifically noting the ties between the biosphere and other Earth systems. For example, when carbon dioxide levels increase in the atmosphere, plants grow more quickly. As their growth continues, they remove more carbon dioxide from the atmosphere. Many scientists are now devoting their careers to organizing new fields of study, such as geobiology and geomicrobiology, to examine these relationships.

For a better understanding of how the biosphere works and various dysfunctions related to human activity, scientists have simulated the biosphere in small-scale models. Biosphere 2 (**Figure** 23.26) is a laboratory in Arizona which contains 3.15 acres of closed ecosystem BIOS-3 was a closed ecosystem in Siberia; and Biosphere J is located in Japan.

Direct human interactions with ecosystems, including agriculture, human settlements, urbanization, forestry, and other uses of land, have fundamentally altered global patterns of biodiversity and ecosystem processes. As a result, vegetation patterns predicted by conventional biome systems are rarely observed across most of the planet's land surface. On terms of the human impact on biomes and ecosystems, the study of ecology is now more important than ever. Scientists that study ecology will move us toward an understanding of how best to live in and manage our biosphere.

Figure 23.26: Biosphere 2, in Arizona, contains 3.15 acres of closed ecosystem and is a small-scale model of the biosphere. (21)

Lesson Summary

- A biome is a climatically and geographically defined area of ecologically similar communities of plants and animals
- Biomes are classified in different ways, sometimes according to patterns of ecological succession and climax vegetation, other times according to differences in the physical environment, and in other situations according to latitude and humidity
- Biodiversity of each biome is a function of abiotic factors, such as moisture availability and temperature, and the biomass productivity of the dominant vegetation
- Terrestrial biomes are defined based on various plant factors and on climate
- Aquatic biomes are classified according to various factors and further subdivided into freshwater and marine biomes
- The most inclusive level of organization in ecology is the biosphere and it is a global ecological system
- The biosphere is itself a living organism, as explained by the GAIA hypothesis
- Humans have fundamentally altered global patterns of biodiversity and ecosystem processes

Review Questions

1. Define a biome.
2. Name a type of biome based on the physical environment.

3. Where would you expect to find more biodiversity, in an equatorial rainforest, or in a southwestern desert? Explain why.
4. Which classification scheme is used to define ecoregions as priorities for conservation?
5. As you climb a mountain, you will see the vegetation a d habitat type change as you gain elevation. How could you see a similar change of habitat types if you were traveling geographically?
6. Name the aquatic biomes classified according to depth.
7. Water is exchanged between the hydrosphere, lithosphere, atmosphere, and biosphere in regular cycles. What role do the oceans play in the biosphere?

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Vocabulary

aquatic biomes Biomes divided into freshwater and marine biomes and defined according to different physical and ecological factors.

biome A climatically and geographically defined area of ecologically similar communities of plants and animals.

biosphere The part of the Earth within which life occurs.

GAIA hypothesis The concept that the biosphere is itself a living organism.

terrestrial biomes Biomes defined based on plant and climatic factors.

Points to Consider

You now have a general idea of what a biome is and how the diversity of a biome is related to other factors; the next chapter, on ecosystem dynamics, will give you a greater understanding of how energy flow, cycling of matter, and succession vary from one biome to another

- One of the aquatic biomes, the hydrothermal vents, mentioned previously in this chapter, is not dependent on sunlight but on bacteria, which utilize the chemistry of the hot volcanic vents; see if you can guess where these bacteria fit into the flow of energy in an ecosystem.

Image Sources

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(17) http://commons.wikimedia.org/wiki/File:Darwin%27s_finches_by_Gould.jpg. Public Domain.

(18) http://commons.wikimedia.org/wiki/File:Hummingbird_nest_with_two_chicks_in_Santa_Monica,_CA._Photo_taken_June_26,_2006.jpg. Public Domain.

(19) Adrian Pingstone. http://commons.wikimedia.org/wiki/File:Bristol.zoo.dead.leaf.mantis.arp.jpg. Public Domain.

(20) Paul Keleher. http://www.flickr.com/photos/pkeleher/987516260/. CC-BY.

(21) http://commons.wikimedia.org/wiki/Image:Biosphere2main.jpg. GNU-FDL.

(22) http://commons.wikimedia.org/wiki/File:Ocellaris_clownfish.JPG. GNU-FDL.

(23) http://commons.wikimedia.org/wiki/File:Monarch_Viceroy_Mimicry_Comparison.jpg. GNU-FDL.

(24) *An example of an aquatic marine biome, pack ice.*. GNU-FDL.

(25) http://commons.wikimedia.org/wiki/File:Amazon_Manaus_forest.jpg. CC-BY-SA 2.5.

(26) http://commons.wikimedia.org/wiki/File:BrantaLeucopsisMigration.jpg. CC-BY-SA 2.5.

Chapter 24

Ecosystem Dynamics

24.1 Lesson 24.1: Flow of Energy

Lesson Objectives

- Explain where all the energy in an ecosystem ultimately comes from.
- Classify organisms on the basis of how they obtain energy (producers, consumers, and decomposers) and describe examples of each.
- Be able to draw and interpret a food web.
- Explain the flow of energy through an ecosystem using an energy pyramid.

Check Your Understanding

- What is photosynthesis?
- What are some examples of organisms that can photosynthesize?
- What is a community?

Introduction

Energy is defined as the ability to do work. In organisms, this work can involve not only physical work like walking or jumping, but also carrying out the essential chemical reactions of our bodies. Therefore, all organisms need a supply of energy to stay alive. Some organisms can capture the energy of the sun, while others obtain energy from the bodies of other organisms. Through predator-prey relationships, the energy of one organism is passed on to another. Therefore, energy is constantly flowing through a community. Understanding how this energy moves through the ecosystem is an important part of the study of ecology.

Energy and Producers

With just a few exceptions, all life on Earth depends on the sun's energy for survival. The energy of the sun is first captured by **producers** (**Figure** 24.1), organisms that can make their own food. Many producers make their own food through the process of photosynthesis. Producers make or "produce" food for the rest of the ecosystem. Therefore the survival of every ecosystem is highly dependent on the stability of the producers. Without producers capturing the energy from the sun and turning it into "food," an ecosystem could not exist. In addition, there are bacteria that use chemical processes to produce food, getting their energy from sources other than the sun, and these are also considered producers.

There are many types of photosynthetic organisms that produce food for ecosystems. On land, plants are the dominant photosynthetic organisms. Algae are common producers in aquatic ecosystems. Single celled algae and tiny multicellular algae that float near the surface of water and that photosynthesize are called phytoplankton.

Although producers might look quite different from one another, they are similar in that they make food containing complex organic compounds, such as fats or carbohydrates, from simple inorganic ingredients. Recall that the only required ingredients needed for photosynthesis are sunlight, carbon dioxide (CO_2), and water (H_2O). From these simple inorganic building blocks, photosynthetic organisms can produce glucose ($C_6H_{12}O_6$) and other complex organic compounds.

Consumers and Decomposers

Many types of organisms are not producers and cannot make their own food from sunlight, air, and water. The animals that must consume other organisms to get food for energy are called **consumers**. The consumers can be placed into several groups. **Herbivores** are animals that eat photosynthetic organisms to obtain energy. For example, rabbits and deer are herbivores that eat plants. The caterpillar in **Figure** 24.2 is a herbivore. Animals that eat phytoplankton in aquatic environments are also herbivores. **Carnivores** feed on animals, either the herbivores or other carnivores. Snakes that eat mice are carnivores, and hawks that eat the snakes are also carnivores. **Omnivores** eat both producers and consumers. Most people are omnivores since they eat fruits, vegetables, and grains from plants and also meat and dairy products from animals. Dogs, bears, and raccoons are also omnivores.

Decomposers (**Figure** 24.3) obtain nutrients and energy by breaking down dead organisms and animal wastes. Through this process, decomposers release nutrients, such as carbon and nitrogen, back into the ecosystem so that the producers can use them. Through this process these essential nutrients are recycled, an essential role for the survival of every ecosystem. Therefore, as with the producers, the stability of an ecosystem also depends on the actions of the decomposers. Examples of decomposers include mushrooms on a decaying log and bacteria in the soil. Decomposers are essential for the survival of every ecosystem. Imagine

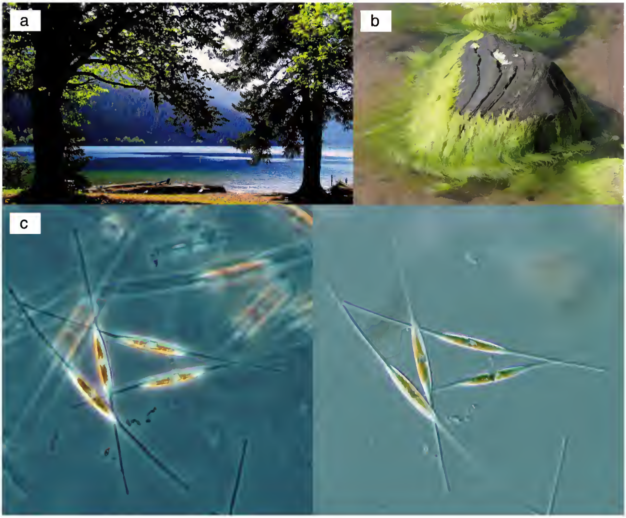

Figure 24.1: Producers include plants (a), algae (b), and diatoms, which are unicellular algae(c). (12)

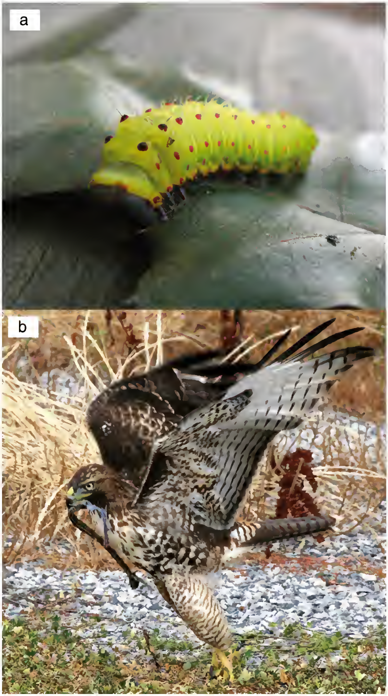

Figure 24.2: Examples of consumers are caterpillars (herbivores) and hawks (carnivore). (3)

what would happen if there were no decomposers. Wastes and the remains of dead organisms would pile up and the nutrients within the waste and dead organisms would never be released back into the ecosystem!

Food Chains and Food Webs

Food chains (**Figure** 24.4) are a visual representation of the eating patterns in an ecosystem, depicting how food energy flows from one organism to another. Arrows are used to indicate the feeding relationship between the animals. For example, an arrow from the leaves to a grasshopper shows that the grasshopper eats the leaves, so energy and nutrients are moving from the leaves to the grasshopper. Next, a mouse might prey on the grasshopper, a snake may eat the mouse, and then a hawk might eat the snake.

In an ocean ecosystem, one possible food chain might look like this: phytoplankton -> krill -> fish -> shark. The producers are always at the beginning of the food chain, followed by the herbivores, then the carnivores. In this example, phytoplankton are eaten by krill, which are tiny shrimp-like animals. The krill are in turn eaten by fish, which are then eaten by sharks. Each organism can eat and be eaten by many different other types of organisms, so simple food chains are rare in nature. There are also many different species of fish and sharks. Therefore, many food chains exist in each ecosystem

Since feeding relationships are so complicated, we can combine food chains together to create a more accurate depiction of the flow of energy within an ecosystem. A **food web** (**Figure** 24.5) shows the complex feeding relationships between many organisms in an ecosystem. If you expand our original example of a food chain, you might also include that deer also eat clover and foxes that also hunt chipmunks. A food web shows many more arrows but follows the same principle; the arrows depict the flow of energy (**Figure** 24.6). A complete food web may show hundreds of different feeding relationships.

Energy Pyramids

When an herbivore eats a plant, the energy that is stored in the plant tissues is used by the herbivore to power its own life processes and to build more body tissues. Only about 10% of the total energy from the plant gets stored in the herbivore's body as extra body tissue. The rest of the energy is transformed by the herbivore through metabolic activity and released as heat. The next consumer on the food chain that eats the herbivore will only store about 10% of the total energy from the herbivore in its own body. This means the carnivore will store only about 1% of the total energy that was originally in the plant. In other words, only about 10% of energy of one step in a food chain is stored in the next step in the food chain.

Every time energy is transferred from one organism to another, there is a net loss of energy. This loss of energy can be shown in an energy pyramid. An example of an energy pyramid

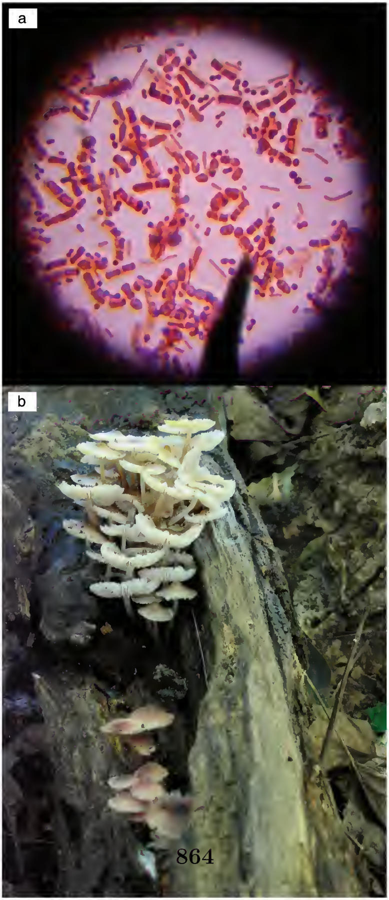

Figure 24.3: Examples of decomposers are bacteria (a) and fungi (b). (1)

Figure 24.4: Food chain. This figure shows, for example, that the snake gets its energy from the rat, and the rat gets its energy from the insect. (17)

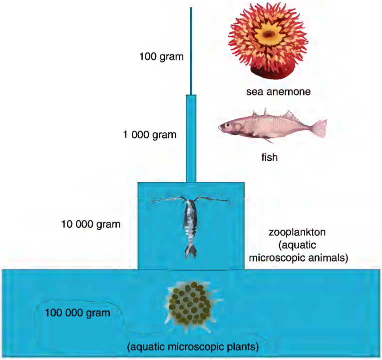

Figure 24.5: Food web in the Arctic Ocean. (16)

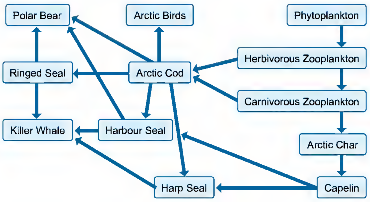

Figure 24.6: Food web in the Arctic Ocean. (9)

is shown in **Figure 6**. Due to the energy loss in food chains, it takes many producers to support just a few carnivores in a community. For example, there are far fewer hawks than acorns in this food chain.

Each step of the food chain reflected in the ecological pyramid is called a **trophic level**. Plants or other photosynthetic organisms are found on the first trophic level, at the base of the pyramid. The next level would be the herbivores, then the carnivores that eat the herbivores. The energy pyramid in **Figure** 24.7 shows only three levels of a food chain, from plants (producers) to hawks (carnivores). Because of the high rate of energy loss in food chains, there are usually only 4 or 5 levels in the chain or energy pyramid.

Lesson Summary

- Producers, which include photosynthetic organisms like plants and algae, can make their own food from simple inorganic compounds.
- Consumers must obtain their nutrients and energy by eating other organisms, while decomposers break down animal remains and wastes to obtain energy.
- Food chains and food webs are visual representations of feeding patterns in an ecosystem.
- As energy is transferred along a food chain, energy is lost as heat.

Review Questions

1. How do decomposers obtain energy?
2. What happens to 90% of the energy that passes from one step in the food chain to the next step?
3. For #'s 3 - 5, Analyze the following food chain: algae -> fish -> herons

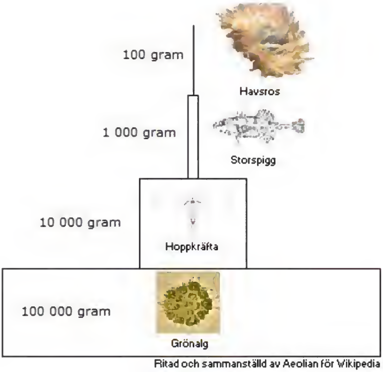

Figure 24.7: As illustrated by this ecological pyramid, it takes a lot of phytoplankton to support the carnivores of the oceans. (4)

4. What is the producer in the food chain?
5. What is the herbivore in the food chain?
6. What is the carnivore in the food chain?
7. In a food chain, does the prey or predator have a greater biomass?
8. In an ecological pyramid, which level would have the greatest biomass?
9. What is the term for the visual representation of complex feeding interactions in a community?
10. In a forest community, caterpillars eat leaves, and birds eat caterpillars. Draw the food chain.
11. What's the term for a consumer that eats both plants and animals?

Further Reading / Supplemental Links

- http://www.eelsinc.org/id43.html
- http://science-class.net/Ecology/energy_transfer.htm
- http://en.wikipedia.org/wiki/Energy_pyramid
- http://curriculum.calstatela.edu/courses/builders/lessons/less/biomes/calcpy.html
- http://science-class.net/Ecology/energy_transfer.htm
- http://en.wikipedia.org/wiki/Food_chain

Vocabulary

biomass The total dry weight of all the individuals of one type of organism.

carnivore An organism that eats other animals.

consumer An organism that must eat other organisms to obtain energy and nutrients.

decomposer An organism that breaks down animal remains or wastes to gain energy and nutrients.

ecological pyramid A visual representation of the energy content or biomass of various levels in a food chain.

food chain A visual representation of the flow of energy from producers to consumers in a community.

food web A visual representation of the complex eating relationships in a community; a cross-linking of food chains.

herbivore A consumer of producers in a community; often organisms that eat plants.

omnivore A consumer in a community that eat both producers and consumers; usually eaters of both plants and animals.

producer An organism that can absorb the energy of the sun and convert it into food through the process of photosynthesis; i.e. plants and algae.

trophic level A level of the food chain reflected in the ecological pyramid.

Points to Consider

- Animals are carbon-based organisms. When animals decompose, what happens to the carbon? Discuss this with your class.
- We need nitrogen to make our DNA. Where does it come from? Where does it go? What would happen to nitrogen released from decaying organisms?
- Water is essential for photosynthesis. Water moves through both the living and non-living parts of an ecosystem. How does water move through the living parts of an ecosystem?

24.2 Lesson 24.2: Cycles of Matter

Lesson Objectives

- Describe the key features of the water cycle.
- Describe the key features of the nitrogen cycle.
- Describe the key features of the carbon cycle.

Check Your Understanding

- What types of organisms break down animal remains and wastes to release nutrients?
- What are the main chemical elements that are essential for life?

Introduction

What happens to all the plants and animals that die? Do they pile up and litter ecosystems with dead remains? Or do they decompose? The role of decomposers in the environment often goes unnoticed, but these organisms are absolutely crucial for every ecosystem. Imagine

if the decomposers were somehow taken out of an ecosystem. The nutrients, such as carbon and nitrogen, in animal wastes and dead organisms would remain locked in these forms if there was nothing to decompose them. Overtime, almost all the nutrients in the ecosystem would be used up. However, these elements are essential to build the organic compounds necessary for life and so they must be recycled. The decomposition of animal wastes and dead organisms allows these nutrients to be recycled and re-enter the ecosystem, where they can be used by living organisms.

The pathways by which chemicals are recycled in an ecosystem are **biogeochemical cycles**. This recycling process involves both the living parts (biotic) of the ecosystem and the non-living (abiotic) parts of the ecosystem, such as the atmosphere, soil, or water. The same chemicals are constantly being passed through living organisms to non-living matter and back again, over and over. Through biogeochemical cycles, inorganic nutrients that are essential for life are continually recycled and made available again to living organisms. These recycled nutrients contain the elements carbon and nitrogen. Water is obviously an extremely important aspect of every ecosystem. Life could not exist without water. Water is also cycled through the biotic and abiotic factors of an ecosystem.

The Water Cycle

Since many organisms contain a large amount of water in their bodies, and some even live in water, the water cycle is essential to life on earth. Water is continually moving between living things and non-living things such as clouds, rivers, or oceans. The water cycle is also important because water is a solvent, so it plays an important role in dissolving minerals and gases and carrying them to the ocean. Therefore, the composition of the oceans is also dependent on the water cycle (**Figure** 24.8).

The water cycle does not have a real starting or ending point, since it is an endless circular process; however, we will start with the oceans. Water evaporates from the surface of the oceans, leaving behind salts. As the water vapor rises, it collects and is stored in clouds. As water cools in the clouds, it condenses into **precipitation** such as rain, snow, hail, sleet, etc. The precipitation allows the water to return again to the Earth's surface. On land, the water can sink into the ground to become part of our underground water reserves, also known as **groundwater**. Much of this underground water is stored in **aquifers**, which are porous layers of rock that can hold water. Most precipitation that occurs over land, however, is not absorbed by the soil and is called **runoff**. This runoff collects in streams and rivers and moves back into the ocean.

Water also moves through the living organisms in the ecosystem. Plants are especially significant to the water cycle because they soak up large amounts of water through their roots. The water then moves up the plant and evaporates from the leaves in a process called transpiration. The process of **transpiration**, like evaporation, returns water back into the atmosphere.

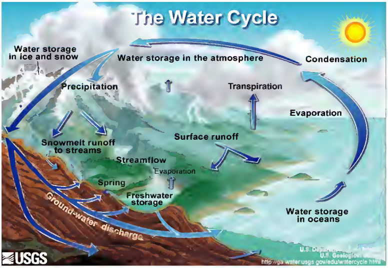

Figure 24.8: The water cycle. See http://www.youtube.com/watch?v=4Cb3SIMRCIE&NR=1 for an animation of the water cycle. (15)

The Carbon Cycle

Carbon is one of the most abundant elements found in living organisms. Carbon chains form the backbones of carbohydrates, proteins, and fats. Carbon is constantly cycling between living things and the atmosphere (**Figure** 24.9).

In the atmosphere, water is in the form of carbon dioxide. Producers capture this carbon dioxide and convert it to food through the process of photosynthesis (discussed in the chapter titled *Cells and Their Structures*). As consumers eat producers or other consumers, they gain the carbon from that organism. Some of this carbon is lost, however, through the process of cellular respiration. When our cells burn food for energy, carbon dioxide is released. We exhale this carbon dioxide and it returns to the atmosphere. Also, carbon dioxide is released to the atmosphere as an organism dies and decomposes.

Millions of years ago there was so much organic matter that it could not be completely decomposed before it was buried. As this buried organic matter was under pressure for millions of years, it formed into **fossil fuels** such as coal, oil, and natural gas. When humans excavate and use fossil fuels, we have an impact on the carbon cycle (**Figure** 24.10). The burning of fossil fuels releases more carbon dioxide into the atmosphere than is used by photosynthesis. Therefore the net amount of carbon dioxide in the atmosphere is rising. Carbon dioxide is known as a greenhouse gas since it lets in light energy but does not let heat escape, much like the panes of a greenhouse. The increase of greenhouse gasses in the atmosphere is contributing to a global rise in Earth's temperature, known as **global warming** (see the *Environmental Problems* chapter for additional information).

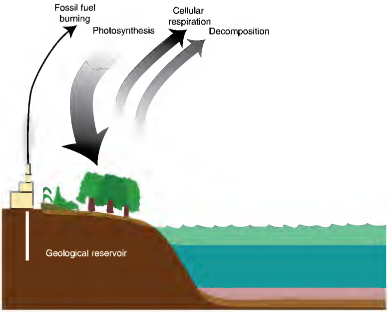

Figure 24.9: The carbon cycle. (10)

Figure 24.10: Human activities like burning gasoline in cars are contributing to a global change in our climate. (13)

The Nitrogen Cycle

Nitrogen is also one of the most abundant elements in living things. It's important for constructing both proteins and nucleic acids like DNA. The great irony of the nitrogen cycle is that nitrogen gas (N_2) comprises the majority of the air we breathe, and yet is not accessible to us or plants in the gaseous form (**Figure** 24.11). In fact, plants often suffer from nitrogen deficiency even through they are surrounded by plenty of nitrogen gas!

In order for plants to make use of nitrogen, it must be converted into compounds with other elements. This can be accomplished several different ways. First, Nitrogen gas can be converted to nitrate (NO_3^-) through lightning strikes. Alternatively, special nitrogen-fixing bacteria can also convert nitrogen gas into useful forms, a process called **nitrogen fixation.** These bacteria live in nodules on the roots of plants in the pea family. In aquatic environments, bacteria in the water can fix nitrogen gas into ammonium (NH_4^+), which can be used by aquatic plants as a source of nitrogen.

Nitrogen also is released to the environment through decaying organisms or decaying wastes. These wastes often take on the form of ammonium. Ammonium in the soil can be converted to nitrate by a two-step process completed by two different types of bacteria. In the form of nitrate, it can be used by plants through a process called **assimilation**.

The conversion of nitrate back into nitrogen gas happens through the work of denitrifying bacteria. These bacteria often live in swamps and lakes. The release of nitrogen gas would equal the amount of nitrogen gas taken into living things if human activities did not influence the nitrogen cycle. These human activities include the burning of fossil fuels, which releases nitrogen oxide gasses into the atmosphere, leading to problems like acid rain.

Lesson Summary

- During the water cycle, water enters the atmosphere through evaporation, and water returns to land through precipitation.
- During the carbon cycle, animals add carbon dioxide to the atmosphere through respiration and plants remove carbon dioxide through photosynthesis.
- During the nitrogen cycle, gaseous nitrogen is converted into water-soluble forms that can be used by plants, while denitrifying bacteria convert nitrate back to gaseous nitrogen.

Review Questions

1. What human activities have thrown the carbon cycle off balance?
2. What biological process "fixes" carbon, removing it from the atmosphere?
3. What is the significance of nitrogen-fixing bacteria?
4. What is the term for the remains of organisms that are burned for energy?

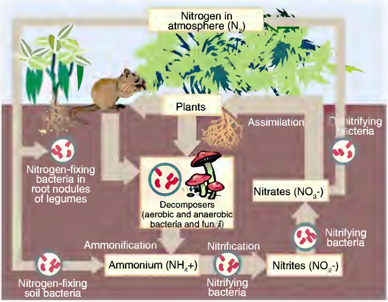

Figure 24.11: The nitrogen cycle includes assimilation, or uptake of nitrogen by plants; nitrogen-fixing bacteria that make the nitrogen available to plants in the form of nitrates; decomposers that convert nitrogen in dead organisms into ammonium; nitrifying bacteria that convert ammonium to nitrates; and denitrifying bacteria that convert help convert nitrates to gaseous nitrogen. (14)

5. How does water in the atmosphere return to the ground?
6. What biological process releases carbon back into the atmosphere?
7. What are some examples of fossil fuels?
8. Why is carbon dioxide referred to as a "greenhouse gas"?
9. What must happen for plants to use nitrogen in the atmosphere?
10. What is the significance of denitrifying bacteria?

Further Reading / Supplemental Links

- http://earthobservatory.nasa.gov/Library/CarbonCycle
- http://www.cosee-ne.net/resources/documents/OceanLiteracyWorkshopIReport.pdf
- http://www.estrellamountain.edu/faculty/farabee/biobk/BioBookcycles.html
- http://earthobservatory.nasa.gov/Library/CarbonCycle
- http://earthguide.ucsd.edu/earthguide/diagrams/watercycle/index.html
- http://en.wikipedia.org/wiki

Vocabulary

assimilation The uptake of nitrogen by plants.

aquifers Layers of porous rock that can hold water underground.

biogeochemical cycles The pathway of elements like carbon and nitrogen through the non-living and living parts of the ecosystem.

denitrifying bacteria Bacteria that convert nitrates or nitrites back to nitrogen in the gaseous form.

fossil fuels Fuels made from partially decomposed organic matter that has been compressed underground for millions of years; examples are: coal, natural gas, and oil.

global warming Global increase in the Earth's temperature due to human activities that release greenhouse gasses into the atmosphere.

groundwater Underground water reserves.

nitrogen fixation Process by which gaseous nitrogen is converted in chemical forms that can be used by plants.

precipitation Water that falls to the earth in the form of rain, snow, sleet, hail.

runoff Water that is not absorbed by the soil that eventually returns to streams and rivers.

transpiration Process by which water leaves a plant by evaporating from the leaves.

Points to Consider

- Do ecosystems change over time? Why or why not?
- Can you think of an example of a ecosystem changing over time?

24.3 Lesson 24.3: Ecosystem Change

Lesson Objectives

- Explain the process of ecological succession.
- Distinguish between secondary and primary succession.
- Describe a climax community.

Check Your Understanding

- What is a biome?
- What is the most abundant element in living things?
- How do humans obtain nitrogen?

Introduction

When you see an established forest, it's easy to picture that the forest has been there forever. This is not the case, however. Ecosystems are dynamic and change over time. That forest may lie on land that was once covered by an ocean millions of years ago. Or the forest may have been cut down at one point for agricultural use, then abandoned and allowed to re-establish itself over time. During the ice ages, glaciers once covered areas that are tropical rainforests today. Due to both natural forces and the influence of humans, ecosystems are constantly changing.

Primary Succession

If conditions of an ecosystem change drastically due to natural forces or human impact, the community of plants and animals that live there may be destroyed or be forced to

relocate. Over time a new community will be established, and then that community may be replaced by another. You may see several changes in the plant and animal composition of the community over time. **Ecological succession** is the continual replacement of one community by another that occurs after some disturbance of the ecosystem.

But ecological succession must also occur on new land, in an area that has not supported life before. **Primary succession** (**Figure** 24.12) is the type of ecological succession that happens in barren lands, such as those created by lava flow or retreating glaciers. Since the land that results from these processes is often completely new land, part of the primary succession process is soil formation.

Primary succession always starts with the establishment of a **pioneer species**, a species that first inhabits the disturbed area. In the case of barren rock, the pioneer species is lichen, a symbiotic relationship between a fungus and an algae or cyanobacteria. The fungus is able to absorb minerals and nutrients from the rock, and the algae or cyanobacteria is provides carbohydrates from photosynthesis. Since the lichen can photosynthesize and do not rely on soil, lichen can live in desolate environments. As the lichen grows, it breaks down the rock, which is the first step of soil formation.

Figure 24.12: Primary succession on a rock often begins with the growth of lichen. (7)

The pioneer species is soon replaced by a series of other communities. Mosses and grasses will be able to grow in the newly created soil. During early succession, plant species like grasses that grow and reproduce quickly will be favored and take over the landscape. Overtime, these plants improve the soil further and a few shrubs can begin to grow. Gradually the shrubs are then replaced by trees. Since trees are more successful competing for resources than shrubs and grasses, a forest will be the end result of primary succession if the climate that supports that type of biome.

Secondary Succession

Sometimes ecological succession occurs in places where there is already soil, and that has previously supported life. **Secondary succession** is the type of ecological succession that happens after something destroys the community, but yet soil remains in the area. One event that can lead to secondary succession is the abandonment of a field that was once used for agriculture (**Figure** 24.13). In this case, the pioneer species would be the grasses that first appear. Gradually the field would return to the natural state and look like it used to look before the influence of man.

Another event that results in secondary succession is a forest fire (**Figure** 24.14 and 24.15). Although the area will look devastated at first, the seeds of new plants are underground and waiting for their chance to grow. Just like primary succession, the burned forest will go through a series of communities, starting with small grasses, then shrubs, and finally mature trees 24.16. An orderly process of succession will always occur, whether a community is destroyed by man or the forces of nature.

Figure 24.13: This land was once used for growing crops. Now that the field is abandoned, secondary succession has begun. Pioneer species, such as the grasses, first appear and then shrubs begin to grow (8)

Climax Communities

Climax communities (**Figure** 24.17) are the end result of ecological succession. In contrast with the series of changes that occur during ecological succession, the climax community is stable. The climax community will remain in equilibrium unless a disaster strikes and succession would have to start all over again.

Figure 24.14: The early stages of succession after a forest fire are shown in these pictures. Taken four years after the fire, they show the charred remains of the original forest as well as the small grasses and shrubs that are beginning to grow back in the area. (2)

Figure 24.15: The early stages of succession after a forest fire are shown in these pictures. Taken four years after the fire, they show the charred remains of the original forest as well as the small grasses and shrubs that are beginning to grow back in the area. (11)

Figure 24.16: In 1988, a forest fire destroyed much of Yellowstone National Park. This photo, taken 17 years later, shows that the forest is gradually growing back. Small grasses first grew here and are now being replaced by small trees and shrubs. This is an example of the later stages of secondary succession. (5)

Depending on the climate of the area, the composition of the climax community is different. In the tropics, the climax community might be a tropical rainforest. At the other extreme, in the northern parts of the world, the climax community might be a coniferous forest. The natural state of the biome defines the climax community.

Lesson Summary

- Ecological succession is the continual replacement of one community by another that occurs after some disturbance of the ecosystem.
- Primary succession occurs in disturbed areas that have no or little soil, while secondary succession occurs in disturbed areas that previously supported life.
- Climax communities are the end product of succession, when the ecosystem is again stable.

Review Questions

1. What is the term for a continuous replacement of one community by another following a disturbance?
2. What type of succession occurs in areas where there is no soil?
3. What type of succession occurs in areas where soil is present?
4. What is the term for the final stage of succession, when the community becomes stable?

Figure 24.17: These ancient redwood trees are part of a climax community, the end result of a series of community replacements during succession. (6)

5. Imagine a forest fire destroyed a forest. The forest will slowly re-establish itself, which is an example of what kind of succession?
6. A glacier slowly melts, leaving bare rock behind it. As life starts establishing itself on the newly available land, what kind of succession is this?
7. Is the climax community look the same in all parts of the world?

Further Reading / Supplemental Links

- http://www.scribd.com/doc/529104/Ecological-Succession
- http://www.biologycorner.com/worksheets/succession.html
- http://ecolibrary.cs.brandeis.edu/general_search.php?id=CS_Succession@Secondary%20succession&page=links
- http://en.wikipedia.org/wiki

Vocabulary

climax communities A stable community that is the end product of succession.

ecological succession The continual replacement of one community by another that occurs after some disturbance of the ecosystem.

primary succession Ecological succession that occurs in disturbed areas that have no or little soil, i.e. after a glacier retreats.

pioneer species The species that first inhabit a disturbed area.

secondary succession Ecological succession that occurs in disturbed areas that have soil to begin with, i.e. after a forest fire.

Points to Consider

- Think about what would happen if dangerous toxins were illegally dumped near a river?
- Discuss why it is important to seek alternative energy sources.
- Do we have an infinite supply of fossil fuels, or can we run out some day?

Image Sources

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(2) http://ecolibrary.cs.brandeis.edu/display.php?id=Succession_four_years_after_forest_fire_2_DP421. CC-BY.

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(8) http://commons.wikimedia.org/wiki/Image:Secondary_succesion_cm02.jpg. GNU-FD.

(9) *Food web in the Arctic Ocean.*.

(10) *The carbon cycle.*. Public Domain.

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(14) http://commons.wikimedia.org/wiki/Image:Nitrogen_Cycle.png. Public Domain.

(15) *The water cycle.*. Public Domain.

(16) *Food web in the Arctic Ocean.*.

(17) CK-12 Foundation. http://commons.wikimedia.org/wiki/Image:FoodChain.svg. GNU-FD.

Chapter 25

Environmental Problems

25.1 Lesson 25.1: Air Pollution

Lesson Objectives

- Discuss the types of outdoor pollution and what causes them.
- Describe the effects of outdoor pollution on the environment.
- Discuss where indoor air pollutants come from and what they are.
- Describe the health hazards of both indoor and outdoor pollutants.
- Discuss how you can protect yourself from air pollution.

Check your Understanding

- Describe the five layers of the Earth's atmosphere (See **Figure** 25.1).
- 1. Exosphere: from 300-600 mi up to 6,000 mi
  2. Thermosphere: from 265,000 – 285,000 ft to 400+ mi
  3. Mesosphere: from about 160,000 ft to the range of 265,000 – 285,000 ft
  4. Stratosphere: from 23,000 – 60,000 ft range to about 160,000 ft; contains most of the ozone layer (with relatively high [a few parts per million] concentrations of ozone – the ozone layer is mainly located from approximately 50,000 to 115,000 ft above Earth's surface)
  5. Troposphere: from the Earth's surface to between 23,000 ft at the poles and 60,000 ft at the equator
- Describe the chemical composition of the atmosphere.
- Explain the significance of the atmosphere.

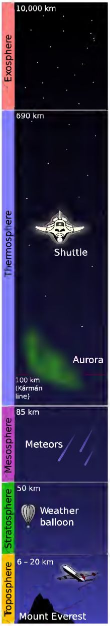

Figure 25.1: The layers of the atmosphere with altitude. (2)

Introduction

Air is all around us and is everywhere and its mix of gases is essential for life. Despite the atmosphere's vastness, human activities, like the emission of chemical substances, particulate matter (smoke and dust), and even biological materials, cause air pollution. This pollution affects entire ecosystems, worldwide. Pollution is also a big problem indoors. Pollution, both the outdoor and indoor varieties, cause many health problems as well as deaths. In spite of all the dangers to human health from pollutants, there are ways for you to protect yourself.

Pollution of Outdoor Air

Air is so easy to take for granted. In its unpolluted state, it cannot be seen, smelled, tasted, felt, or heard, except when it blows or during cloud formation. Yet its gases are very important for life: nitrogen helps build proteins and nucleic acids, oxygen helps to power life, carbon dioxide provides the carbon to build bodies, and water has many unique properties which most forms of life depend on.

Outdoor air pollution consists of either chemical, physical (e.g. particulate matter), or biological agents that modify the natural characteristics of the atmosphere and cause unwanted changes to the environment and to human health. **Primary pollutants** are added directly to the atmosphere by such processes as fires (**Figure** 25.2) or combustion of fossil fuels (**Figure** 25.3), such as oil, coal, or natural gas (**Figure** 25.4). **Secondary pollutants** are formed when primary pollutants interact with sunlight, air, or each other. Both types are equally damaging.

Figure 25.2: Wildfires, either natural- or human-caused, release particulate matter into the air, one of the many causes of air pollution. (20)

Most air pollutants can be traced to the burning of fossil fuels. These include the burning

Figure 25.3: A major source of air pollution is the burning of fossil fuels from factories, power plants, and motor vehicles. Photo was taken prior to installation of emission controls equipment for removal of sulfur dioxide and particulate matter. (13)

Figure 25.4: The majority of air pollutants can be found in the burning of fossil fuels for heat, electricity, industry, waste disposal, and transportation, the latter seen here on a busy highway. (33)

of fuels in power plants to generate electricity, in factories to make machinery run, in stoves and furnaces for heating, in various modes of transportation, and in waste facilities to burn waste. Even before the use of fossil fuels since the Industrial Revolution, wood was burned for heat and cooking in fireplaces and campfires, and vegetation was burned for agriculture and land management.

In addition to the burning of fossil fuels, other sources of human-caused (**anthropogenic**) air pollution are agriculture, such as cattle ranching, fertilizers, herbicides and pesticides, and erosion; industry, such as production of solvents, plastics, refrigerants, and aerosols; nuclear power and defense; landfills; mining; and biological warfare.

Environmental Effects of Outdoor Air Pollution

Many outdoor air pollutants may impair the health of plants and animals (including humans). There are many specific problems caused by the burning of fossil fuels. For example, sulfur oxides from coal-fired power plants and nitrogen oxides from motor vehicle exhaust cause **acid rain** (**Figure** 25.5) (precipitation or deposits with a low pH). This has adverse effects on forests, freshwater habitats, and soils, killing insects and aquatic life.

Figure 25.5: A forest in the Jizera Mountains of the Czech Republic shows effects attributed to acid rain. At higher altitudes, effects of acid rain on soils combines with increased precipitation and fog to directly affect foliage. (9)

Global warming (an increase in the earth's temperature) is thought to be caused mostly by the increase of **greenhouse gases** (water vapor, carbon dioxide, methane, ozone, chlorofluorocarbons (CFCs), nitrous oxide, hydrofluorocarbons, and perfluorocarbons) via the **greenhouse effect** (the atmosphere's trapping of heat energy radiated from the Earth's surface).

Water vapor causes about 36-70% of the greenhouse effect and carbon dioxide causes 9-26%. Fossil fuel burning has produced approximately three-quarters of the carbon dioxide from human activity over the past 20 years, while most of the rest is due to land-use change, particularly deforestation (**Figure** 25.6). Methane causes 4-9% of the greenhouse effect and ozone causes 3-7%. Some other naturally occurring gases contribute very little to the greenhouse effect; one of these, nitrous oxide, is increasing in concentration due to an increase in such human activities as agriculture.

Figure 25.6: Deforestation, shown here as a result of burning for agriculture in southern Mexico, has produced significant carbon dioxide production over the past 20 years. (38)

The effect of global warming is to increase the average temperature of the Earth's near-surface air and oceans. This increase in global temperature will cause the sea level to rise and is expected to cause an increase in intensity of extreme weather events and to change the amount and pattern of precipitation. Other effects of global warming include changes in agricultural yields, trade routes, glacier retreat, and species extinctions.

Other environmental problems caused by human-caused air pollution include **global dimming** (a reduction in the amount of radiation reaching the Earth's surface) and **ozone depletion** (the latter being two related declines in stratospheric ozone). Particulate matter from the burning of wood and coal and **aerosols** (airborne solid particles or liquid droplets) cause global dimming, by absorbing solar energy and reflecting sunlight back into space. Environmental effects of global dimming include less photosynthesis, resulting in less food for all trophic levels; less energy to drive evaporation and the hydrologic cycle; and cooler ocean temperatures, which may lead to changes in rainfall and drought.

Ozone is both a benefit and detriment. As a component of the upper atmosphere, it has

shielded all life from as much as 97-99% of the lethal solar ultraviolet (UV) radiation. However, as a ground-level product of the interaction between pollutants and sunlight, ozone itself is considered a pollutant which is toxic to animals' respiratory systems.

Ozone depletion consists of both losses in the total amount of ozone in the Earth's stratosphere – about 4% per year from 1980 to 2001, and the much larger loss, the **ozone hole,** a seasonal decline over Antarctica. A secondary effect of ozone depletion is a decline in stratospheric temperatures. The pollutants that are responsible for ozone depletion are CFCs, from the use of aerosol sprays, refrigerants (Freon), cleaning solvents, and fire extinguishers.

Ozone depletion and the resulting increase in levels of UV radiation reaching Earth could result in the reduced abundance of UV-sensitive nitrogen-fixing bacteria, which cause a disruption of nitrogen cycles, and a loss of plankton, causing a disruption of ocean food chains.

Pollution of Indoor Air

Lack of indoor ventilation and circulation concentrates air pollution in places where people often spend a majority of their time, and allows them to accumulate more than they would otherwise occur in nature. Some of these indoor pollutants include radon gas, released from the Earth in certain locations and then trapped inside buildings; formaldehyde gas, emitted from building materials, such as carpeting and plywood; volatile organic compounds (VOCs) are given off by paint and solvents as they dry; and lead paint, which can degenerate into dust.

Other air pollutants are caused by the use of air fresheners, incense, and other scented items. Wood fires in stoves and fireplaces can produce significant amounts of smoke particulates into the air. Use of pesticides and other chemical sprays indoors, without proper ventilation, can be another source of indoor pollution.

Carbon monoxide (CO) is often released by faulty vents and chimneys, poorly adjusted pilot lights, or by the burning of charcoal indoors. Flaws (non-functioning built-in traps) in domestic plumbing can result in emission of sewer gas and hydrogen sulfide. Dry cleaning fluids, such as tetrachloroethylene, can be emitted from clothing, days after dry cleaning. The extensive use of asbestos in industrial and domestic environments in the past has left a potentially very dangerous material in many localities (**Figure** 25.7).

Biological sources of air pollution, such as gases and airborne particulates, are also found indoors. These are produced from pet dander; dust from minute skin flakes and decomposed hair; dust mites (which produce enzymes and micrometer-sized fecal droppings) from bedding, carpeting, and furniture; methane from the inhabitants; mold (which generates mycotoxins and spores) from walls, ceilings, and other structures; air conditioning systems, can incubate certain bacteria and mold; and pollen, dust, and mold from houseplants, soil, and surrounding gardens.

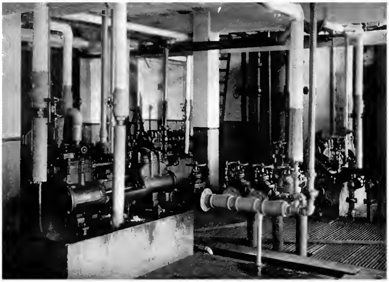

Figure 25.7: The extensive use of asbestos in industrial (as pictured here, asbestos-covered pipes in an oil-refining plant) and domestic environments in the past has left a potentially very dangerous material in many localities. (12)

Health Hazards of Air Pollution

The World Health Organization (WHO) states that 2.4 million people die each year from causes directly related to air pollution, and 1.5 million of these deaths caused by indoor sources. One study has shown a strong correlation between pneumonia-related deaths and air pollution caused by motor vehicles. Worldwide, there are more deaths linked to air pollution per year than to car accidents. Research by WHO also shows that the greatest concentration of particulate matter particles exists in countries with high poverty and population rates, such as Egypt, Sudan, Mongolia, and Indonesia.

Direct causes of air-pollution related deaths include aggravated asthma, bronchitis, emphysema, lung and heart diseases, and respiratory allergies. The U.S. Environmental Protection Agency (EPA) estimates that a set of proposed changes in technology of diesel engines could result each year in the U.S. in 12,000 fewer mortalities, 15,000 fewer heart attacks, 6,000 fewer visits to the emergency room by children with asthma, and 8,900 fewer respiratory-related admissions to the hospital.

Health effects caused by air pollution may range from subtle physiological and biochemical changes to difficulties in breathing, wheezing, coughing, and aggravation of existing cardiac and respiratory conditions. These conditions can result in increased use of medications, visits to the doctor or emergency room, more admissions to the hospital, and premature deaths. Individual reactions to air pollution depends on the type of pollutant, the degree of exposure, and the individual's medical condition.

Certain respiratory conditions can be made worse in people who live closer or in large metropolitan areas. In one study, it was found that such patients had higher levels of pollutants found in their system because of more emissions in the larger cities. In patients with the disease of cystic fibrosis, patients already born with decreased lung function, had worse lung function as a result of such pollutants as smoke emissions from automobiles, tobacco smoke, and improper use of indoor heating devices. Some studies have shown that patients in urban areas suffer lower levels of lung function and more self diagnosis of chronic bronchitis and emphysema.

Because children are outdoors more they are more susceptible to the dangers of air pollution. Children living within cities with high exposure to air pollutants are at risk to develop asthma, pneumonia and other lower respiratory infections.

In addition to respiratory and heart-related ailments, air pollution can also cause an increase in cancer, eye problems, and other conditions. For example, use of certain agricultural herbicides and pesticides, such as DDT (an organic pesticide) and PCBs (poly-chlorinated biphenyls), use of some industrial solvents and plastics, radioactive waste, use of some indoor materials like asbestos, and ozone depletion can all cause cancer.

Smog, caused by coal burning, and ground-level ozone produced by motor vehicle exhaust can cause eye irritation, as well as respiratory problems, and ozone depletion can cause an increased incidence of cataracts. Carbon monoxide from motor vehicle exhaust and from faulty vents and chimneys and charcoal burning indoors can cause poisoning and fatalities. Mercury released from coal-fired power plants and from medical waste can cause neurotoxicity (poisoning to nerve tissue).

Protecting Yourself from Air Pollution

After reading the above sections, you may be confused as to where the air is healthier, outdoors or indoors? While it is not always possible to know what exact steps you should take under any situation, common sense often plays a role. For example, if you hear in the news that the outdoor air quality is particularly bad, then it might make sense to either wear masks outdoors or to stay indoors as much as possible at such times, especially if you already have such respiratory conditions as asthma, for example. Because you have more control over your indoor air quality than the outdoor air quality, there are some simple steps you can take indoors to make sure the air quality is less polluted.

Perhaps you could review the section, "Pollution of Indoor Air" above, and come up with some ideas for how you could reduce indoor air pollution. For example, make sure your house is well ventilated and there is circulation of air. Try to avoid use of toxic substances in the home; always read labels to see what warnings about toxic ingredients are listed. If you are not sure about a particular product, use either outdoors or in a well-ventilated room and avoid direct inhalation. Use of medical supply masks is also helpful to protect yourself further.

Make sure that vents, chimneys, and vents are working properly and never burn charcoal indoors. Carbon monoxide detectors can be placed in the home, if carbon monoxide emission is of concern. In addition, keeping your home as clean as possible from pet dander, dust, dist mites, and mold, and making sure air conditioning systems are working properly can minimize effects on asthma and other respiratory problems. Are there any other ways you can think of to protect yourself from air pollution?

Lesson Summary

- Outdoor air pollution consists of either chemical, physical, or biological agents that modify the natural characteristics of the atmosphere and cause unwanted changes to the environment and to human health.
- There are two kinds of pollutants: primary and secondary pollutants.
- There are many sources of human-caused air pollution, the most common being the burning of fossil fuels.
- Outdoor air pollutants cause many environmental effects, among them global warming, global dimming, and ozone depletion.
- Indoor air pollutants are either chemical or biological in nature.
- Both outdoor and indoor pollutants cause many health problems, ranging from respiratory and cardiac to cancer, eye problems, and poisoning.
- While it is not always possible to protect yourself from poor air quality outdoors, there are a number of measures you can take to protect yourself from poor indoor air quality.

Review Questions

1. Define outdoor air pollution.
2. Most air pollutants can be traced to the burning of fossil fuels. What were the sources of such pollutants before the Industrial Revolution?
3. Why does deforestation contribute to an increase in global warming?
4. Explain why one of the environmental effects of global dimming may result in less food at all trophic levels.
5. Name two environmental effects of ozone depletion.
6. There is no direct evidence linking ozone depletion to a higher incidence of skin cancer in human beings. Give an explanation for this.

Further Reading / Supplemental Links

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- http://www.epa.gov/region5/students/air.htm
- http://www.epa.gov/acidrain/education/site_students/
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en.wikipedia.org/wiki

Vocabulary

acid rain Precipitation or deposits with a low (acidic) pH.

aerosols Airborne solid particles or liquid droplets.

air The mixture of gases present in the atmosphere.

anthropogenic Human-based causes.

atmosphere A layer of gases that surrounds the planet; composed of five layers.

global dimming A reduction in the amount of radiation reaching the Earth's surface.

global warming The recent increase in the Earth's temperature.

greenhouse effect The atmosphere's trapping of heat energy radiated from the Earth's surface.

greenhouse gases The cause of global warming by certain gases via the greenhouse effect.

outdoor air pollution Chemical, physical, or biological agents that modify the natural characteristics of the atmosphere and cause unwanted changes to the environment and to human health.

ozone depletion Reduction in the stratospheric concentration of ozone.

ozone hole A seasonal decline of ozone over Antarctica.

primary pollutants Substances released directly into the atmosphere by processes such as fire or combustion of fossil fuels.

secondary pollutants Substances formed when primary pollutants interact with sunlight, air, or each other.

Points to Consider

- One of the effects of outdoor air pollution is to cause global warming. Global warming, in turn, has an effect on both land and sea. Think about how the effects of global warming on the amount and pattern of precipitation will have an effect on water pollution.
- Environmental effects of global dimming include less energy to drive evaporation and the hydrologic cycle, and cooler ocean temperatures, which may lead to changes in rainfall and drought. Will such changes affect water pollution?
- Some outdoor air pollutants have a direct effect on aquatic habitats. For example, acid rain can adversely affect freshwater habitats.

25.2 Lesson 25.2: Water Pollution and Waste

Lesson Objectives

- Describe water pollution sources.
- Explain how water pollution affects living organisms.
- Discuss how to prevent water pollution.
- Discuss ways you can save water.

Check your Understanding

Water pollution obviously has to do with water.

- What are water resources?
- What is the demand for water?
- What are the sources of fresh water?

Answers

- Surface water is water found in rivers, lakes, or freshwater wetlands. It is naturally replenished by precipitation and naturally lost through discharge to evaporation, discharge to the oceans, and sub-surface (groundwater) seepage.
- Groundwater is the water flowing within **aquifers** (a geological formation that contains or conducts groundwater, especially for supplying water for wells, etc.). The natural input to groundwater is seepage from surface water and the natural outputs are to springs and seepage to bodies of water.
- Desalination is an artificial process by which saline water (usually sea water) is converted to fresh water. Only a very small amount of total water use is supplied by desalination.

- Frozen water found in icebergs has not been found to be a reliable water source. Glacier runoff is a source for surface water.

Introduction

While water may seem limitless and everywhere – after all, you can turn your faucet and out it comes, without appearing to dry up – in fact, in the United States it is a limited resource, and in many parts of the world, even scarce. Add to this the necessity of having water without pollution and you can see that unpolluted water is even harder to find (**Figure** 25.8).

Water pollution is the contamination of water bodies by contaminants, mostly anthropogenic, and causing a harmful effect on living organisms. As you explore in this lesson how water pollution affects living things, you will see the urgency in preventing water pollution and discover ways to save water. Perhaps you will be inspired to think of how your household, community, and even world can be a model to others to not take clean water for granted!

Sources of Water Pollution

Although natural phenomena such as storms, algal blooms, volcanoes, and earthquakes can cause major changes in water quality, human-caused contaminants have a much greater impact on the quality of the water supply. Water is considered polluted either when it does not support a human use (like clean drinking water) or undergoes a major change in its ability to support the ecological communities it serves.

The primary sources of water pollution can be grouped into two categories, depending on the point of origin:

A. **Point source pollution** refers to contaminants that enter a waterway or water body through a single site. Examples of this includes discharge (also called effluent) of either untreated sewage or wastewater from a sewage treatment plant, industrial effluent, leaking underground tanks, or any other discrete sources of nutrients, toxins, or waste.
B. **Nonpoint source pollution** refers to contamination that does not originate from a single point source, but is often a cumulative effect of small amounts of contaminants (such as nutrients, toxins, or wastes) gathered from a large area. Examples of this include runoff in rainwater of soil, fertilizers (nutrients) or pesticides from an agricultural field, soil from forested areas that have been logged, toxins or waste from construction or mining sites, and even fertilizers or pesticides from your own backyard!

Specific contaminants causing water pollution include a wide variety of chemicals, and pathogens (disease-causing substances). While many of the chemicals and substances that

Figure 25.8: Water pollution can cause harmful effects to ecology and human health. (1)

are regulated may be occurring naturally (iron, manganese, etc.) it is often the concentration of the substance that determines what is a natural component of water and what is a contaminant.

In addition to toxic substances and disease-causing ones, alteration of water's physical chemistry, including acidity, electrical conductivity, and temperature, can also have an effect.

Effects of Water Pollution on Living Things

Water pollutants can have an effect on both the ecology of aquatic ecosystems as well as on human health. Let's examine several types of pollution problems and how they affect both the ecology and human health.

Polution Problem: Eutrophication

Definition: An increase in chemical nutrients, specifically compounds containing nitrogen or phosphorus, in an ecosystem.

Causes: Frequently a result of nutrient pollution such as the release of sewage effluent and run-off from lawn fertilizers into natural waters, such as rivers or coastal waters.

Effect on Ecology: Excessive growth of aquatic vegetation or phytoplankton (or *algal bloom* and decay, and a lack of oxygen, the latter causing severe reductions in water quality, fish, and shellfish.

Effect on Human Health and Well-Being:

- Decreases the resource value of rivers, lakes, and estuaries to adversely affect recreation, fishing, hunting, and aesthetic enjoyment.
- If nitrogen is leached into groundwater, drinking water can be affected because nitrogen concentrations are not filtered out.
- Biotoxins created during algal blooms are taken up by shellfish, such as mussels or oysters; if humans eat these shellfish, then shellfish poisoning can occur and you can become extremely sick, including paralysis and other neurological conditions.

Polution Problem: Ocean Acidification

Definition: A process whereby the oceans' uptake of anthropogenic carbon dioxide from the atmosphere causes an ongoing decrease in pH of the oceans (see "Points to Consider," Lesson 25.1: Air Pollution, showing a possible link of air pollutants to water pollution).

Causes: Human actions such as land-use changes and the combustion of fossil fuels can lead to an increase in carbon dioxide into the atmosphere, some of which is then absorbed by the oceans

Effect on Ecology: Decrease in pH primarily affects oceanic calcifying organisms, such as corals and shellfish; may also directly affect reproduction or other physiology of marine organisms or indirectly cause negative impacts through their food resources

Effect on Human Health and Well-Being: No likely effects

Polution Problem: Transformation of Chemicals

Definition: Transformation of many chemicals, including chlorinated hydrocarbons (carcinogens), especially over long periods of time in groundwater.

Causes: Chemicals are used in industrial metal degreasing and electronics manufacturing and find their way into the groundwater or other waterways.

Effect on Ecology: As they undergo change in groundwater, can lead to new hazardous chemicals.

Effect on Human Health and Well-Being: Such contaminated groundwater can poison drinking water and lead to various human health problems, including cancer.

Polution Problem: Aquatic Debris

Definition: Aquatic debris (or trash) in fresh and saltwater waterways.

Causes: Shipping accidents, Landfill erosion, or dumping of trash.

Effect on Ecology: Aquatic wildlife swallowing plastic bags, strangulation by plastic six-pack rings, entanglement of wildlife in nets (**Figure** 25.11).

Effect on Human Health and Well-Being: Adversely affects recreation and aesthetic enjoyment.

Let's close this section and look at a few other effects of water pollution on human health. According to the World Health Organization (WHO), diarrheal disease is responsible for the deaths of 1.8 million people every year. It was estimated that 88% of that burden is attributed to unsafe water supply, sanitation, and hygiene, and is mostly concentrated in the children of developing countries.

Such **waterborne diseases** can be caused by protozoa, viruses, bacteria, and intestinal parasites. Protozoal infections can be caused by sewage, non-treated drinking water, animal manure, poor disinfection, and groundwater contamination; some viruses and bacteria are water-borne and can be found in drinking water, sewage, contaminated seafood, or unsanitary recreational water; and parasitic infections are usually caused by contaminated drinking water.

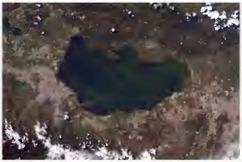

Figure 25.9: Lake Valencia, Venezuela, showing vivid green algal blooms, resulting from continued influx of untreated wastewater from surrounding urban, agricultural, and industrial land uses. This contributes to ongoing eutrophication, contamination, and salinization of the lake This pollution impacts the lake's use as a reservoir for the surrounding urban centers and limits opportunities for tourism and recreational uses as well. (10)

Figure 25.10: Marine debris can adversely impact all sorts of aquatic life. Pictured here is a marine turtle entangled in a net. (31)

Figure 25.11: Intercepting nonpoint pollution between the source and waterway has been found to be successful. Pictured here, a bioretention cell, or rain garden, in the U.S, is designed to treat polluted storm water runoff from an adjacent parking lot. (4)

Preventing Water Pollution

In the U.S., concern over water pollution resulted in the enactment of state anti-pollution laws in the latter half of the 1800s, and federal legislation in 1899, which prohibited the disposal of any refuse matter into the nation's navigable rivers, lakes, streams, and other bodies of water, unless a person first had a permit. In 1948, the Water Pollution Control Act was passed and gave authority to the Surgeon General to reduce water pollution.

Growing public awareness and concern for controlling water pollutants led to enactment of the Federal Water Pollution Control Act Amendments of 1972, later amended in 1977, to become commonly known as the Clean Water Act. This Act established the basics for regulating discharge of contaminants and established the authority for the U.S. Environmental Protection Agency (EPA) to implement standards for wastewater discharge by industry. The Clean Water Act also continued requirements to set water quality standards for all surface water contaminants.

More specifically, control of point sources of phosphorus through policy changes have resulted in rapid control of eutrophication. Nonpoint sources, on the other hand, are more difficult to regulate and usually vary with season, precipitation, and other irregular events. Nonpoint sources are especially troublesome because of soil retention, runoff to surface water and leaching to groundwater, and the effect of acid rain (See the Air Pollution lesson).

On the hopeful side, though, cleanup measures have been somewhat successful. For example, Finnish removal of phosphorus started in the mid-1970s has targeted rivers and lakes polluted by industrial and municipal discharges. These efforts have had a 90% efficiency in removal. And with nonpoint sources, some efforts, like intercepting pollutants between the source and water, are successful (**Figure** 25.12). Also, creating buffer zones near farms and roads is another possible way to prevent nutrients from traveling into waterways.

In addition, laws regulating the discharge and treatment of sewage have led to dramatic nutrient reductions to aquatic ecosystems, but a policy regulating agricultural use of fertilizer and animal waste must also be imposed. One technique (Soil Nitrogen Testing, or N-Testing) helps farmers optimize the amount of fertilizer applied to crops and at the same time decreases fertilizer application costs, decreases the nitrogen lost to surrounding water resources, and sometimes decreases both.

Actions aimed at lessening eutrophication and algal blooms are usually desirable. However, the focus should not necessarily be aimed at eliminating blooms, but towards creating a sustainable balance that maintains or improves ecosystem health. As you will see in the next lesson (25.3): Natural Resources, sustainable use is a useful concept for the use of resources as well. Can you think of some reasons why?

Figure 25.12: A water purification system at Bret Lake, Switzerland. Contaminants are removed and clean new water is created. (32)

Ways to Save Water

While we will deal further with this topic in the next Lesson (25.3) on Natural Resources, we will examine here how saving water can also contribute to maximizing clean water for future use. In addition, preventing water pollution is one way of preserving precious water resources.

One way to make sure that water is kept clean and conserved is the use of wastewater reuse or cycling systems, including the recycling of wastewater to be purified at a water treatment plant. By that means, many of the waterborne diseases, caused by sewage and non-treated drinking water, can be prevented.

There are also various means of water purification, whereby contaminants are removed from a raw water source and at the same time create clean new water. Atmospheric water generation is one technology that can provide high quality drinking water by extracting water from the air by cooling the air and thus condensing the water vapor.

Reclaimed water, or recycled water (**Figure** 25.13) that is treated and allowed to recharge the aquifer, is used for non-drinking purposes, so that potable water is used for drinking. This helps to conserve high quality water.

Another way to reduce water pollution and at the same time conserve water is via **catchment management.** This is used to recharge groundwater supplies, helps in the formation of groundwater wells, and eventually reduces soil erosion, one cause of pollution, due to running water.

In addition, both developed and developing countries can increase protection of ecosystems,

Figure 25.13: Sand processing Mill, near Provodin, Czech Republic. Water is used to wash mined sand, then is drained into tanks, filtered, and recycled. (17)

especially wetlands and riparian zones (areas located on the bank of a waterway, like a river, or sometimes along a lake or tidewater). Not only do these measures conserve biota, but they can also make more effective the natural water cycle flushing and transport that make water systems more healthy for humans. What are some ways you can save water in your own house or community in order to increase the resource of clean water, to be made available to everyone?

Lesson Summary

- There are two primary sources of water pollution, point source and nonpoint sources.
- Specific contaminants causing water pollution include chemicals, pathogens, and physical or sensory changes.
- Water pollution can affect both ecology and human health.
- One effect of water pollution is eutrophication, which can cause detrimental effects on aquatic ecosystems as well as on human life, including health.
- Water pollution also causes ocean acidification, which impacts oceanic calcifying organisms.
- Contaminated groundwater can lead to poisoned drinking water and various health problems, including cancer.
- A variety of water pollutants can cause waterborne diseases.
- Various legislation has regulated discharge of contaminants into water resources and led to dramatic nutrient reductions, but more can be done, especially in areas such as

the agricultural use of fertilizer and animal waste.
- Different ways of saving water can also have an impact on our clean water supply.

Review Questions

1. When is water considered polluted?
2. Name some sources of nonpoint source pollution.
3. Lakes often become polluted as a result of point source pollution release of phosphorus from sewage plants. By what process would the release of phosphorus affect a lake's vegetation growth and how would this in turn affect reductions in water quality and fish and shellfish populations?
4. Name some sources of pollutants that can cause waterborne diseases.
5. Why are nonpoint sources of pollution so difficult to regulate?
6. Why might floating plastic debris be a problem for marine life?

Further Reading / Supplemental Links

- Unabridged Dictionary, Second Edition, Random House, New York, 1998.
- http://www.epa.gov/region5/students/water.htm
- http://www.cdli.ca/CITE/water.htm
- http://www.epa.gov/region5/students/waste.htm
- http://en.wikipedia.org

Vocabulary

algal bloom Excessive growth of aquatic vegetation or phytoplankton as a result of eutrophication.

aquifers Geological formations that contain or conduct groundwater.

catchment management Method used to recharge groundwater supplies, help in the formation of groundwater wells, and reduce soil erosion.

desalination An artificial process by which saline water is converted to fresh water.

eutrophication An increase in nutrients, specifically compounds containing nitrogen or phosphorus, in an ecosystem.

frozen water Found in icebergs and glaciers.

nonpoint source pollution Contaminants resulting from a cumulative effect of small amounts of contaminants gathered from a large area.

ocean acidification Process whereby the oceans' uptake of anthropogenic carbon dioxide from the atmosphere causes an ongoing decrease in ocean pH.

point source pollution Contaminants that enter a waterway or water body through a single site.

surface water Water found in rivers, lakes, or freshwater wetlands.

waterborne diseases Diseases caused by organisms transmitted via contaminated water.

water pollution The contamination of water bodies by substances, mostly anthropogenic, which cause a harmful effect on living organisms.

Points to Consider

- Even though water is a renewable resource, there is not always availability of clean water. Control of water pollution, such as removal of phosphorus or creating buffer zones near farms, helps to preserve this renewable resource for the future.
- Methods such as wastewater reuse, atmospheric water generation, reclaiming water, catchment management, and protection of aquatic systems can all contribute towards the dual goals of keeping water clean and also available for future generations.

25.3 Lesson 25.3: Natural Resources

Lesson Objectives

- Explain what natural resources are.
- Describe renewable resources.
- Explain what nonrenewable resources are.
- Discuss the use of fossil fuels as an energy source and what energy sources are available as alternatives.
- Discuss how reducing, reusing, and recycling can help conserve resources.

Check your Understanding

- What are our natural resources?
- What is the difference between a renewable and nonrenewable resource?

Introduction

There are many **natural resources** all about us. Which ones seem the most obvious? Which do you use on a regular basis? Which do you think you could keep using and they would never run out? After thinking about some of these resources, you will see how important an understanding is about what we do use in our daily lives, which of these resources will run out, and what we can do in our daily lives to help prevent them from running out.

As we also examine our energy needs, we will see that fossil fuels are only one source of energy. Just because we use these on a daily basis does not make them necessarily the best choice. What are some of the benefits and detriments to using fossil fuels for energy? Can you think of some alternative energy sources that make the most sense, both from an energy point of view, and also economically? Finally, what can you do, in your home, school, and community to reduce unnecessary use of resources, and to reuse and recycle them when possible?

What are Natural Resources?

A natural resource is a naturally occurring substance which is necessary for the support of life. The value of a natural resource depends on the amount of the material available and the demand put upon it by organisms.

What resources do you use on a daily basis? The ones that may come to mind right away are the ones we already looked at in the last two lessons: air and water. What else is absolutely necessary to your survival? The food you eat seems pretty obvious. Could you survive with just air, water, and food? Are other resources, like the land you live on, the house you live in, the gasoline your parents put in the car and the tools you use at home or at school absolutely necessary for survival and if not, should they be considered resources too?

As you start thinking about what are natural resources for humans, compare these to what are natural resources for organisms other than humans. Perhaps it might seem a bit clearer as to what are resources for other organisms, since their lives are much simpler than ours and they really use resources for survival rather than for making their lives more desirable.

As we will see later in this lesson, of all living organisms, humans have the greatest impact on natural resources. Therefore it is our responsibility to make sure we do everything we can to use resources wisely.

Renewable Resources

A resource is renewable if it is replenished by natural processes at about the same rate at which humans use it up. Examples of this are sunlight and wind (**Figures** 25.14 and 25.15), which are very abundant resources and in no danger of being used up. Tides are another

example of a resource in unlimited supply, as well as **hydropower**, which is renewed by the Earth's hydrologic cycle.

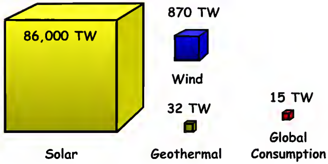

Figure 25.14: Solar radiation and wind energy are considered renewable resources because availability of both far exceeds our rate of consumption. 89,000 TW (terawatts) represents the amount of sunlight that falls on the Earth's surface, 370 TW depicts wind energy available, and 15 TW was the global rate of energy consumption in 2004. (21)

Figure 25.15: Wind power, another renewable resource, shown here in a modern wind energy plant. (22)

Based on what you learned in the last two lessons, would you say air and water are renewable resources? They may appear to be, but your knowledge about air and water pollution would tell you that clean air and water are not always so accessible. As we think about other

resources, like soils, plants and animals, minerals, and energy resources let's keep in mind about whether these are truly renewable or not.

For example, soils are often considered renewable, but because of **erosion** and mineral depletion, this is not always the case (**Figure** 25.16). Living things, like forests and fish, are considered renewable because they can reproduce to replace individuals lost to human consumption. However, overexploitation of these resources can lead to extinction.

Figure 25.16: Soil (Stagnogley) as a resource, showing a mixture of eroded rock, minerals, ions, partially decomposed organic material, water, air, roots, fungi, animals, and microorganisms, formed over thousands, possibly millions of years. (29)

Also think about at what costs resources can be renewed. If something can be renewed, but at great cost economically or ecologically, is that resource still considered renewable? Perhaps a better way to put this is, does it make sense to renew a resource at great cost? If you're thinking that this discussion is leading up to energy resources, you would be right!

For example, energy resources derived from living things, such as ethanol, plant oils, and methane, are considered renewable, but the environmental costs are not always adequately considered. We will be discussing fossil fuels and alternative energy sources further in this lesson.

Other renewable materials would include **sustainable** (at a rate which meets the needs of the present without impairing future generations from meeting their needs) harvesting of wood, cork, and bamboo, as well as sustainable harvesting of crops. Also, metals and other minerals are sometimes considered renewable because they can be recycled, and are not destroyed when they are used.

Nonrenewable Resources

A **nonrenewable resource** is a natural resource that exists in fixed amounts (relative to our time frame) and can be consumed or used up faster than it can be made by nature. It cannot be regenerated or restored on a time scale compared to its consumption. Two main types of nonrenewable resources are fossil fuels and nuclear power.

- **Fossil fuels,** such as petroleum, coal, and natural gas:

1. Have formed from plant remains (for coal) and phyto- and zoo-plankton remains (for oil) over periods from 50 to 350 million years ago!
2. Has been estimated that 20 metric tons of phytoplankton produce one liter of gasoline!
3. Have been consuming fossil fuels for less than 200 years, yet remaining reserves of oil can supply our needs for only 45 years; of gas, for only 72 years; and of coal, for 252 years

- **Nuclear power**

1. Limited uranium fuel supplies; could last 70 years at current rates of use.
2. Known and unknown reserves are probably much larger.
3. New technologies could make some reserves more useful.

Population growth; industrialization, especially in developing countries; and advances in technology place increasing pressures on how fast we consume natural resources. An unequal distribution of wealth, technology, and energy use suggest that developing nations will even further their increase of demands on natural resources (**Figure** 25.17).

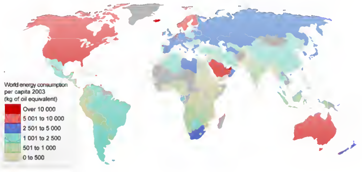

Figure 25.17: Per capita energy consumption (2003) shows the unequal distribution of wealth, technology, and energy use. (26)

That is not to say that all is doom and gloom either. Improvements in technology, conservation of resources, and controls in population growth could all help to lessen the demand on natural resources.

Fossil Fuels and Alternative Energy Sources

As you learned in the section on nonrenewable resources, fossil fuels, such as petroleum, coal, and natural gas, exist in fixed amounts, take millions of years to form naturally, and cannot be replaced as fast as they are consumed. They range from very volatile (explosive) materials like methane, to liquid petroleum to nonvolatile materials like coal.

It was estimated in 2005 that 86% of primary energy production in the world came from burning fossil fuels. Concern about fossil fuels is one of the causes of regional and global conflicts, and the production and use of fossil fuels raise concerns about the environment.

A global movement toward the generation of alternative energy sources, which are renewable, is therefore under way to help meet increased energy needs. Some of these, like solar radiation, wind energy, and hydropower, were mentioned briefly in the section on renewable resources. Let's discuss these and others now in more detail.

- **Solar power** (**Figure** 25.18) involves using solar cells to convert sunlight into electricity. When sunlight hits solar thermal panels, it is converted to heat water or air. It can also be used to heat water (producing steam) via a parabolic mirror, or it can be used for passive solar heating of a building simply by passing through windows.

Figure 25.18: An example of solar power, using solar cells to convert sunlight into electricity. (16)

- **Wind power,** the conversion of wind energy into forms such as electricity via wind turbines, is only used for less than 1% of the world's energy needs. However, growth in harvesting wind energy is rapid, with recent annual increases of more than 30%.

- Hydropower (**Figure** 25.19) uses the energy of moving water to turn turbines or water wheels, which drive a mechanical mill or an electric generator. Today, the largest use of hydropower is for electric power generation, which allows low cost energy to be used at long distances from the water source. Electricity can also be generated constantly, as long as sufficient water is available, it produces no primary waste or pollution, and it is a renewable resource.

Figure 25.19: Small hydropower plant, Buchholz, Switzerland. (36)

Other alternative energy sources to the burning of fossil fuels include **geothermal power; biomass, biofuels; tidal power;** nuclear energy; and **fusion power.** Let's examine these briefly to see how they compare with the sources of energy we've already discussed. Keep in mind as we do so what you think the best alternatives might be.

- Geothermal power uses the natural flow of heat from the earth's core to produce steam, which is used to drive turbines, which, in turn, power electric generators.
- Biomass production involves using garbage or other renewable resources such as corn or other vegetation to generate electricity. When garbage decomposes, the methane produced is captured in pipes and burned to produce electricity. Advantages of these types of energy include using organic waste products from agriculture; biomass is abundant and is generally renewable.
- Power can be extracted from Moon-gravity-powered tides by locating a water turbine in a tidal current. The turbine can turn an electrical generator, or a gas compressor, which can then store energy until needed (**Figure** 25.20).
- Nuclear power plants use nuclear fission to generate energy inside a nuclear reactor. The released heat, heats water to create steam, which spins a turbine generator, producing electricity (**Figure** 25.21).

Figure 25.20: Dam of the tidal power plant on the estuary of the Rance River, Bretagne, France (37)

Figure 25.21: Aerial photo of the Bruce Nuclear Generating Station near Kincardine, Ontario (15)

Now that we have reviewed the pros and cons of fossil fuels and alternative energy sources, what type or types do you think makes the best use of the natural resources available to us? As we move into our last section, also think about how reducing waste and reusing and recycling resources can help us reach our goals for energy production as well.

Reduce, Reuse, and Recycle

When we think of **reducing**, we're talking about reducing our output of waste. That could also mean cutting down on use of natural resources. Reusing and recycling are other ways we can cut down on use of resources.

Minimizing of waste may be difficult to achieve for individuals and households, but here are some starting points that you can include in your daily routine:

- When you go shopping for items, buy quantities you know you will use without waste; sometimes buying larger may be a better deal, cost-wise, but make sure you will really finish what you buy
- To minimize usage of electricity, turn lights off when not using and replace burned out bulbs with ones that are more ecologically efficient
- Reduce water use by turning off faucets when not using water; use low-flow shower heads, which save on water and use less energy, since less water is being heated; use low-flush and composting toilets
- Purchase water-efficient crops, which require little or no irrigation
- Put kitchen and garden waste into a compost pile
- In the summer, change filters on your air conditioner and keep your thermostat at a temperature as warm as you can tolerate; in winter, make sure your furnace is working properly, keep the temperature as cold as you can tolerate, and make sure there is enough insulation on windows and doors
- Mend broken or worn items, when feasible
- Walk or bicycle to destinations, when possible, rather than using an automobile, in order to save on fuel costs and to cut down on emissions
- When buying a new vehicle, check into hybrid and semi-hybrid brands (many new ones are coming rapidly onto the market) to cut down on gas mileage
- Consider which makes more sense – to spend valuable gas to go further to recycle, for example, or to sometimes use the trash instead of recycling

Let's now look at what we can **reuse**. Reusing includes using the same item again for the same function and also using an item again for a new function. Reuse can have both economic and environmental benefits. New packaging regulations are helping society to move towards these goals.

Some ways of reusing resources (think about ways these might be incorporated into your home) include:

- Use of gray water – water which has been used for laundry or washing, for example, can be used to water the garden or flush toilets * At the town level, sewage water can be used for fountains, watering public parks or golf courses, fire fighting, and irrigating crops that will be peeled or boiled before use

- Catching of runoff, which will also slow nonpoint source pollution and erosion – rain barrels next to buildings, recharge pits to re-fill aquifers

Perhaps you can think of some other ways to reuse resources!

Now we move on to **recycling.** Sometimes it may be difficult to understand the differences between reuse and recycling. Recycling differs in that it breaks down the item into raw materials, which are then used to make new items, whereas reusing uses the same item again. Even though recycling requires extra energy, it does often make use of items which are broken, worn out, or otherwise unsuitable for reuse.

The things that are commonly recycled include aggregates and concrete, batteries, biodegradable waste, electronics, iron and steel, aluminum, glass, paper, plastic, textiles, timber, industrial breaking of ships, and tires. Each type of recyclable requires a different technique. Perhaps you or your school could arrange for a trip to a recycling plant!

Here are some things you can do to recycle in your home, school, or community:

- If you have recycling in your community, make sure you separate out your plastics, glass, and paper, according to your local guidelines; have containers set up for easy placement
- See if your school recycles; if not perhaps you and some friends could start a recycling, or ecology, club, or organize efforts to better recycling goals

In order to judge the environmental and economic benefits of recycling, the cost of this process must be compared to the costs of extracting the original resource. In order for recycling to make economical sense, there usually must be a steady supply of recyclables and constant demand for the reprocessed products. Government legislation can stimulate both of these. As with all environmental issues, individuals can communicate with their representatives to make sure their wishes are heard.

The amount that an individual wastes is small in proportion to all waste produced by society. Yet all small contributions, when added up, can make a difference. In addition, influence on policy can be exerted in other areas. Awareness by you and your family, for example, of the impact and power of certain purchasing and recycling decisions can influence manufacturers and distributors to avoid buying products that do not have eco-labeling, are currently not mandatory, or that minimize the use of packaging.

Lesson Summary

- A natural resource is a naturally occurring substance which is necessary for the support of life.
- Resources are either renewable or nonrenewable.
- Examples of renewable resources include sunlight, wind tides, and hydropower.

- Some resources may seem to be renewable, but may have some limits, as to how accessible a nonpolluted resource is and what effect overexploitation of the resource has.
- Some renewable materials include the sustainable harvesting of certain products.
- Nonrenewable resources include fossil fuels and nuclear power.
- Burning of fossil fuels causes harmful effects in the environment and can lead to regional and global conflicts.
- There are a number of renewable energy sources which offer alternatives to the burning of fossil fuels; they include solar radiation; wind energy; hydropower; geothermal power; biomass, biofuels, and vegetable oil; tidal power; nuclear energy; and fusion power.
- There are pros and cons to all alternative energy sources.
- Reducing waste and the reusing and recycling of resources can help save natural resources as well as help us reach our goals for energy production.
- There are many things you can do in your household and community towards the goals of reducing, reusing, and recycling; individual efforts can also add up to make a difference nationally, and even internationally.
- Awareness of wise resource use at the consumer level can influence decisions at the manufacturing and distributing levels.
- Government legislation is also important to enforce these changes; it is up to individuals to communicate to their representatives the carrying out of wise use of natural resources, and to vote for those leaders who stand for sound ecological practices.

Review Questions

1. Under what conditions is a resource renewable?
2. Why must some natural renewable resources, such as geothermal power, fresh water, timber, and biomass be carefully managed?
3. Why is nuclear power considered a nonrenewable resource?
4. With resources that have limited supplies, what human factors put increasing pressure on how fast we consume such resources?
5. What are the main disadvantages to the burning of fossil fuels as an energy source?
6. What two advantages do solar power, wind power, and hydropower all have in common?

Further Reading / Supplemental Links

- Unabridged Dictionary, Second Edition, Random House, New York, 1998.

Natural Resources

- http://dnr.state.il.us/lands/education/index.htm
- http://www.nrcs.usda.gov/feature/education/squirm/skworm.html

- http://fossil.energy.gov/education/energylessons/index.html
- http://www1.eere.energy.gov/education/report_resources.html
- http://www.epa.gov/region5/students/waste.htm
- http://en.wikipedia.org/wiki/Water_conservation

Vocabulary

biofuels The production of fuels, such as wood or ethanol, from biomass.

biomass Use of garbage or other renewable resources such as corn or other vegetation to generate electricity.

erosion Process by which the surface of the Earth is worn away by the action of winds, water, waves, glaciers, etc.

fossil fuels Formed from plant or animal remains over periods from 50 to 350 million years ago and used to produce sources of energy, such as petroleum and coal.

fusion power The production of atomic energy by the process of nuclear fusion.

geothermal power The use of the natural flow of heat from the Earth's core to produce steam.

hydropower Use of power from falling water or other water movement to generate and distribute electricity; also known as hydroelectric power.

natural resources Naturally occurring substances necessary for the support of life.

nonrenewable resource A natural resource that exists in fixed amounts and can be consumed or used up faster than it can be made by nature.

nuclear power A nonrenewable resource, where nuclear fission is used to generate energy.

recycling The breaking down of an item into raw materials to make new items.

reducing Minimizing the use of resources.

renewable resources Resources that are replenished by natural processes at about the same rate at which they are used.

solar power The use of solar cells to convert sunlight into electricity.

sustainable A rate which meets the needs of the present without impairing future generations from meeting their needs.

tidal power Power generated from tidal currents.

wind power The conversion of wind energy into electricity via wind turbines.

Points to Consider

- Minimizing use of some resources helps to preserve habitats; for example, conservation of human water use helps to preserve freshwater habitats for local wildlife and migrating waterfowl.
- Habitats are another resource for both humans and other organisms. Now that we have considered conservation of natural resources, we will move on in the next lesson to examining the effects of habitat destruction and how to protect habitats. Why do you think this is an important topic?
- Discuss how the protection of natural resources may be important for biodiversity.
- Protection of natural resources, including habitats, is also important to avoid dire consequences, such as extinction of species. Discuss why.

25.4 Lesson 25.4: Habitat Destruction and Extinction

Lesson Objectives

- Discuss what causes destruction of habitats.
- Explain why habitat destruction threatens species.
- Describe causes of extinction other than habitat destruction.
- Explain why biodiversity is important.
- Explain why habitat protection is important, including for maintaining biodiversity.

Check your Understanding

- What is a habitat?
- What is habitat destruction?
- What is the effect of habitat destruction?
- What is biodiversity? (**Figures** 25.22, 25.23 and 25.24.)

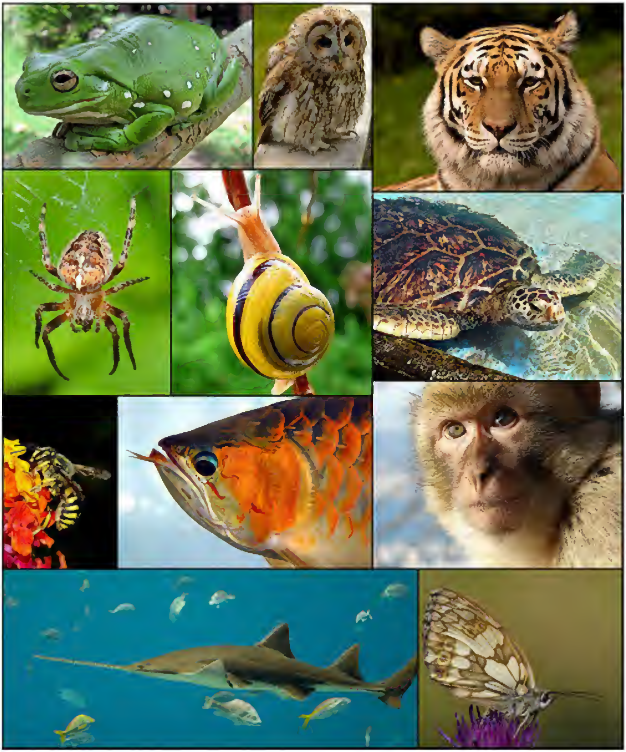

Figure 25.22: A sampling of some of the wide diversity of animal species on earth. (35)

Figure 25.23: Coral reefs are one of the biomes with the highest biodiversity on earth. (34)

Figure 25.24: This tropical rain forest demonstrates another biome having one of the greatest biodiversities on earth. (28)

Introduction

From a human point of view, a habitat is the environment where you live, go to school, places where you go to have fun, and other places you regularly visit. Maybe if we think of habitat in this way we will have a better sense of other species' habitats and a better appreciation for how valuable a habitat is to its occupants.

When we likewise consider habitat destruction, we might evaluate more carefully human influences such as land clearing (**Figure** 25.25) and introduction of non-native species of plants and animals and how this can have even catastrophic effects, like **extinction** of species (**Figure** 25.26), some of which give us great beauty and some of which have medicinal or other useful qualities! In human terms, how would we feel if someone came in and radically changed our habitat, and either drove us out or worse yet, caused us to eventually die?

Figure 25.25: Slash-and-burn agriculture, shown here in southern Mexico, clears land for agriculture. (23)

In this lesson, we will also examine other causes of extinction besides habitat destruction and the importance of biodiversity. Finally, we will see, that as our planet becomes more threatened and as we see how this also impacts the human species, human awareness of these issues has led to measures, such as habitat protection, that can help all of the earth's inhabitants.

Figure 25.26: An exotic species, the brown tree snake, hitch-hiked on an aircraft to the Pacific Islands, causing the extinctions of many bird and mammal species which had evolved in the absence of predators. (24)

Causes of Habitat Destruction

Clearing some habitats of vegetation for purposes of agriculture and development is a major cause of habitat destruction or loss. Within the past 100 years, the area of cultivated land worldwide has increased 74%. Land for the grazing of cattle has increased 113%! Agriculture, alone, has cost the United States 50% of its **wetlands** (**Figure** 25.27) and 99% of its **tallgrass prairies** (**Figure** 25.28). Native prairie ecosystems, with their thick fertile soils, deep-rooted grasses, diversity of colorful flowers, burrowing prairie dogs and burrowing owls, herds of bison and pronghorn antelope, and other animals, are virtually extinct (**Figure** 25.29).

Another habitat that is being rapidly destroyed is forests, most significantly tropical rainforests, one of the two major ecosystems (or biomes) with the highest biodiversity on earth. The largest cause of deforestation today is **slash-and-burn agriculture** (**Figure** 25.25), practiced by over 200 million people in tropical forests throughout the world. Depletion of the thin and nutrient-poor soil (even so, biodiversity here is high – can you guess why?) often results in people abandoning the forest within a few years, and subsequent erosion can lead to **desertification** (a process leading to production of a desert of formerly productive land [usually at least semi-arid]).

Half of the earth's mature tropical forests are gone. At current rates of deforestation, all tropical forests will be gone by 2090. Poverty, inequitable land distribution, and overpopulation combine in many developing countries to add pressure to habitats which are already stressed. Use of firewood, charcoal and manure for cooking and other energy needs, and waste of crops further degrade environments, threatening biodiversity through habitat loss.

Figure 25.27: Wetlands such as this one in Cape May, New Jersey, filter water and protect coastal lands from storms and floods. (18)

Figure 25.28: Big bluestem grasses as tall as a human were one of the species of the tallgrass prairie, largely eliminated by agricultural use. (11)

Figure 25.29: Herds of bison also made up part of the tallgrass prairie community. (14)

Other causes of habitat destruction include poor fire management, invasion of pest and non-native species, overfishing, mining, pollution, and storm damage.

Why Habitat Destruction Threatens Species

Agriculture, forestry, mining, and urbanization have disturbed over half of the earth's land. Inevitably, species disappear and biodiversity decreases. Habitat destruction is currently ranked as the most important cause of extinction of species worldwide.

The destruction of a species' habitat may alter the landscape to such an extent that the species is no longer able to survive and becomes extinct. This may occur directly, such as the environment becoming toxic, or indirectly by limiting a species' ability to compete effectively for diminished resources or with a new species.

Habitat destruction through pollution can kill off a species very rapidly, by killing all living members by contamination or sterilization. It can also occur over longer periods at lower toxicity levels, by affecting life span, reproductive capability, or competitiveness.

Habitat destruction can also occur physically by elimination of certain niches in a habitat. For example, elimination of dense tropical rainforest and replacement with open pastureland can affect certain species. Thus, a fern that depends on dense shade for protection from direct sunlight can no longer survive without trees to shelter it. Another example of this is the destruction of ocean floors by bottom trawling.

Fewer resources or introduction of new competitor species often accompany habitat destruction. Global warming has allowed some species to expand their ranges, sometimes into those of species that previously occupied that area. If these new competitors are predators, they

may directly affect prey species, or they may compete with other species for limited resources. If such resources as water and food are limited during habitat destruction, then species can become extinct.

Another type of habitat that is being rapidly destroyed is the wetland. By the 1980s, over 80% of all historic wetlands in seven states of the U.S. were filled, at which time Congress acted to create a policy of "no net loss" of wetlands. In Europe, extensive loss of wetlands has resulted in loss of biodiversity. For example, many bogs in Scotland have been drained or developed because of human population expansion. Over half of the Portlethen Moss in Aberdeenshire, for example, has been lost and a number of species, such as the great crested newt, are no longer present.

Another example of species loss due to habitat destruction occurred on Madagascar's central highland plateau. From 1970 to 2000, slash and burn agriculture eliminated about 10% of the country's total native biomass and converted it to a barren wasteland. Adverse effects included widespread gully erosion that produced heavily silted rivers and eliminated a large amount of usable fresh water. Much of the riverine ecosystems of several large west-flowing rivers were also destroyed, several fish species have been driven to the edge of extinction, and some coral reef formations in the Indian Ocean are effectively lost.

Practices such as clear-cutting of old growth forests, strip mining (**Figure** 25.30), and drift-net fishing can go beyond the harvesting of a single species or resource to degrade entire ecosystems. Overexploitation happens on the level of genes and ecosystems as well as individual species. Forest plantations, fish hatcheries and farms, and intensive agriculture reduce both species diversity and genetic diversity within species.

Figure 25.30: Strip coal mining, pictured here, has degraded the entire ecosystem. (6)

Other Causes of Extinction

One of the primary causes of extinction (already mentioned briefly) is introduction of exotic species (alien or **invasive species**). Both intentionally and inadvertently, humans have introduced various species into habitats, which already have their own native species. As a result, these invasive species have often had very harmful effects on the native species.

As long ago as 3500 BC, ships from Polynesian times brought crop species and domesticated animals as well as stowaway rats and snakes. Recently cargo ships have transported zebra mussels, spiny waterfleas, and ruffe into the Great Lakes via ballast water ((**Figure** 25.31). Europeans brought purple loosestrife and European buckthorn to North America to beautify their gardens.

Figure 25.31: These zebra mussels, an introduced species, colonize most man-made and natural surfaces, including native mussels. Here they have infested the walls of the Arthur V. Ormond Lock, on the Arkansas River. They have caused significant damage to American waterways, locks, and power plants. (19)

Other invasive species have included the European starling, introduced by Shakespeare enthusiast Eugene Schieffelin to Central Park in the 1890s, because he thought Americans should experience every bird mentioned in the works of Shakespeare. This species is a hole-nesting species and has affected native species where it has been introduced (i.e. Australia, North America) because of competition for nest sites. Other examples of invasive species include the introduction of the cane toad, introduced to control the cane beetle, and the brown tree snake (**Figure** 25.26).

Many of these exotic species, away from the predation or competition of their native habitats, have unexpected and negative effects in the new ecosystems. Introduced species can disrupt

food chains, carry disease, prey on native species directly, and as we have already seen, out-compete natives for limited resources. All of these effects can lead to extinctions of the native species. In addition, some introduced species hybridize with native species, resulting in **genetic pollution,** which weakens natural adaptations.

Another major cause of extinction is global climate change. As we have already seen earlier in this chapter, our increasing reliance on fossil fuels in altering the earth's atmosphere, and as a result, climate. This has many effects, some of which we have already discussed, but on a species level, these other effects, including changing air and water temperatures, rainfall patterns, and salinity threaten species adapted to pre-warming conditions and thus result in a decline of biodiversity globally.

Overpopulation (already mentioned previously), along with developments in technology, have added tremendous pressure to resource and land use and add to all of the previously mentioned threats to biodiversity. The highest rates of population growth are often in third world tropical countries where biodiversity is also highest. Therefore pressures from local populations as well as increased pressure from incoming tourists in some areas can produce enormous consequences for the local plant and animal ecosystems.

A final major cause of extinction is pollution, and mentioned earlier in this lesson. Pollution adds chemicals, noise, heat, or even light beyond the capacity of the environment to absorb them without major harmful effects on all kinds of organisms.

One good example of a toxic chemical affecting a species was the use of the pesticide, DDT. Use of this pesticide in the eastern United States resulted in the effect of **biological magnification** (where many synthetic chemicals concentrate as they move through the food chain, so that toxic effects are multiplied), with the result of the disappearance of the peregrine falcon from this area. As a result, DDT was banned in the U.S.

Pollution continues to contribute to habitat destruction and decreasing biodiversity worldwide, especially in developing countries. Air pollution knows no boundaries and as we have already seen, its effects on acid rain, ozone depletion, and global warming all affect biodiversity.

Water pollution especially threatens vital freshwater and marine resources throughout the world. Specifically, industrial and agricultural chemicals, waste, acid rain, and global warming threaten waters, essential for all ecosystems. Finally, soil contamination, mostly from toxic industrial and municipal wastes (**Figure** 25.32), salts from irrigation, and pesticides from agriculture all degrade soils, the foundation of terrestrial ecosystems and their biodiversity.

Outside the developed world, pollution controls often lag far behind those of the U.S. and Europe, and some developing nations, like China, are rapidly increasing their levels of pollution. Many pollution problems are also present in industrialized nations as well; industry and technology add nuclear wastes, oil spills (**Figure** 25.33), thermal pollution from wastewater, acid rain, and more to the challenges facing the earth's biodiversity (**Figure** 25.34).

Figure 25.32: Soil contamination caused by underground storage tanks containing tar. (8)

Figure 25.33: An oiled bird from an oil spill in San Francisco Bay. About 58,000 gallons of oil spilled from a South Korean-bound container ship when it struck a tower supporting the San Francisco-Oakland Bay Bridge in dense fog, 11/07. (25)

Figure 25.34: A highly endangered Macquarie perch specimen was caught on a lure with barbless hooks in a high altitude upland river and was carefully released. This species is now extinct in most of its upland river habitats due to introduced trout species in the same habitats. Siltation from agricultural practices and flow regulation and thermal pollution by dams have also caused the extinction of this species in some upland rivers. (3)

Importance of Biodiversity

Does it matter if we are losing thousands of species each year, when the earth holds millions and life has been through extinction before? The answer is yes; it matters even if we consider only direct benefits to humans. But there are also lots of indirect benefits, also known as ecosystem services, in addition to benefits to other species as well.

Biodiversity is important for a number of reasons. Economically, direct benefits include the potential to diversify our food supply; increase resources for clothing, shelter, energy, and medicines; a wealth of efficient designs which could inspire new technologies; models for medical research; and an early warning system for toxicity.

In our food supply, monocultures (large-scale cultivation of single varieties of single species) are very vulnerable to disease. As recently as 1970, blight affected the corn belt where 80% of maize grown in the U.S. was of a single type (**Figure** 25.35). Contemporary breeders of various crop species increase the genetic diversity by producing hybrids of crop species with wild species adapted to local climate and disease.

As many as 40,000 species of fungi, plants, and animals provide us with many varied types of clothing, shelter, and other products. These include poisons, timber, fibers, fragrances, papers, silks, dyes, adhesives, rubber, resins, skins, furs, and more. In addition to these above raw materials for industry, we use animals for energy and transportation, and biomass for heat and other fuels.

According to one survey, 57% of the most important prescription drugs come from nature (bacteria, fungi, plants, and animals) (**Figure** 25.36), yet only a fraction of species

Figure 25.35: In order to increase the genetic diversity of corn, these unusually colored and shaped Latin American maize are bred with domestic corn lines. Such hybrids have the potential for increased productivity, nutritional value, adaptation to local climates, and resistance to local diseases. (7)

with medicinal properties have been examined. **Bionics**, also known as biomimetics or biomimicry, uses organisms as models for engineering inspiration. For example, rattlesnake heat-sensing pits suggest infrared sensors and Zimbabwe's Eastgate Centre (**Figure** 25.37) was inspired by the air-conditioning efficiency of a termite mound (**Figure** 25.38).

Figure 25.36: Aspirin originates in the bark of the white willow, pictured here. (27)

Figure 25.37: Design of this Eastgate Centre, in Zimbabwe, which requires just 10% of the energy needed for a conventional building of the same size was inspired by a biological design (See Figure 17). (30)

At an ecological level, biodiversity provides ecosystem stability and productivity; the maintenance and renewal of soils, water supplies, and the atmosphere; nitrogen fixation and nutrient recycling; pollination, pest, and disease control; and waste disposal. Other benefits include the cultural, aesthetic, and spiritual values of biodiversity and its importance to many types of recreation.

Biodiversity is critically important for us and for the earth, and it is declining at a fast rate. What can you do to help to protect habitats, which are at the crux of biodiversity?

Protecting Habitats

There are lots of things we can do to protect biodiversity, some of which we've touched upon in prior sections of this lesson, including the need to reduce, reuse, and recycle of all resources; not contributing to introduction of invasive species; practicing sustainable management on your own land; adopting and spreading sustainable perspectives and philosophy; learning more about biodiversity; and taking action as a citizen to make sure biodiversity is protected.

We are going to focus now on what can be done, or has already been done, to protect habitats, the actual physical spaces, themselves, which, as we have seen, contributes to maintaining and increasing biodiversity. What do you think helps protect habitats and what can you do to help protect them?

Perhaps if you've taken a trip, or even in your own community, you've enjoyed some time

Figure 25.38: The air-conditioning efficiency of this termite mound was the inspiration for the Eastgate Centre (Figure 16). (5)

exploring and enjoying the outdoors. Think of the areas you might have visited that seemed, even somewhat, undisturbed, in other words, areas where there was little disturbance from human influence. Maybe you were able to enjoy scenic landscape, enjoy some quiet where you could hear the sounds of nature, or maybe see very few people. Sometimes we need to get away from all the noise and pollution and be in a quiet place, not only to enjoy and appreciate the nature around us, but even to experience some quiet within ourselves.

If you think back on some of these places, what characteristics of the actual physical location did you observe? Does it require a huge amount of space to protect a habitat, or will even a small space do? From what we know about habitats and species, how much space is enough to ensure species will not become extinct or threatened?

There may not be a clear answer to this. It really depends on the species involved and what its requirements are. A large mammal, like a species of big cat, who has a large range, may need more land than a much smaller species, like a snail. Often, if we protect the habitat of a keystone species (See the *From Populations to the Biosphere chapter, Lesson on Communities*), which usually has a larger habitat than all the other species in that community, then all the other habitats of other species within that community will be protected as well.

The kinds of protected areas, we are talking about, that help protect species are usually in the form of national parks, nature reserves, state parks, and even community and town parks. Sometimes it is important to also protect interconnecting corridors between parks or reserves to protect those species that travel from one area to another for purposes of breeding or feeding, for example.

Even though many of these protected areas are already in existence, there is much you can do as a citizen to make sure these areas stay protected and to help create other areas that need to be protected. Some of the things you can do are to get involved with your community or town's efforts to protect local areas. Even if you don't understand everything that goes on at a town meeting, you might want to attend one sometime to learn about some of the important local environmental issues that are being discussed.

Join local groups which monitor ecosystem health, such as Frog Watch, River Watch, or bird counts. Some national organizations have programs, such as National Audubon's Great Backyard Bird Count and Operation Feeder Watch, and similar programs run by the National Wildlife Foundation, where you can keep track of what you see in your backyard and thereby contribute to a greater understanding of biodiversity.

Become aware of some of the habitat issues on a state and national level. Maybe you can write or e-mail your state representatives, for example, to urge them to help protect areas large enough to accommodate migration, flooding, buffer zones, pollution from nearby development, and even people and their activities. It is a challenge to balance the needs of an increasing population with natural resource needs, but we have to remember that people, as well as wildlife, depend on natural resources to flourish and survive!

Volunteer with local organizations that protect habitat. Help out at cleanup days in your

community, where people gather together to pick up trash and make a habitat more hospitable for its inhabitants. Some of these cleanup days are even advertised through your school. Start an ecology club at your school, if there isn't one already, and encourage your friends and classmates to join.

Think about sustainable management even at the level of your own backyard, even if it is a small yard. What does your household do with organic waste? Do you have a compost pile or would you or your family consider starting one? What kinds of trees and shrubs are planted in your yard? Are they native or introduced species? Drought-tolerant? Research some of the vegetation you can plant that will attract native bird, mammal, and other species. Put out bird feeders, especially in the winter in areas where birds may have trouble finding food, but make sure you keep the feeders well-stocked with food. Similarly, bird baths are useful, especially when temperatures get warm and during dry periods. Use organic or natural pesticides and fertilizers.

Remember that in addition to all the actions you can take, even learning about biodiversity and ecology is an important part of valuing and protecting the diversity of life. Pass on what you learn to others.

Lesson Summary

- There are a number of causes of habitat destruction, including clearing of land, introduction of invasive species, overfishing, mining, pollution, and storm damage.
- Habitat destruction threatens species through pollution, eliminations of niches, availability of fewer resources, and introduction of new species.
- Some habitats affected by destruction include tropical rainforests, wetlands, and coral reefs.
- Introduction of invasive species have caused harmful effects on native species, sometimes resulting in extinction
- Other causes of extinction include pollution, global climate change, and overpopulation.
- Biodiversity is important because it directly affects humans as well as ecosystem benefits and benefits to other species.
- Economically, biodiversity diversifies our food supply; increases resources for clothing, shelter, and energy, and medicines; inspires new technologies; supplies models for medical research and an early warning system for toxicity.
- Because of the importance of biodiversity and habitats, it is vital to do what we can do as citizens to protect habitats; these include continued protection in national parks, reserves, and other green areas; creation of new areas; communicating with representatives about these issues; volunteering with local organizations which have these goals in mind; and practicing sustainable practices, even at the level of your own backyard! Most importantly, educate others about the importance of habitat protection.

Review Questions

1. What is the largest cause of deforestation today?
2. How can habitat destruction through pollution kill a species over a long period of time?
3. Why do introduced exotic species have unexpected and negative effects in the new ecosystems?
4. Why are so many exotic species now being introduced either accidentally or intentionally to native habitats?
5. Explain how biological magnification played a role in the disappearance of the peregrine falcon from the eastern U.S.
6. Loss of biodiversity limits our ability to increase the genetic diversity of crops. What is the advantage of producing hybrids of crop species with wild species adapted to local climate and disease?
7. What are some of the things you can do to have a sustainably managed backyard?

Further Reading / Supplemental Links

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- http://www.fws.gov/endangered/kids/index.html
- http://www.blm.gov/education/LearningLandscapes/students.html
- http://www.epa.gov/owow/oceans/kids.html
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- http://ology.amnh.org/biodiversity
- http://www.biodiversity911.org
- http://en.wikipedia.org

Vocabulary

biodiversity The number of different species or organisms in an ecological unit (i.e. biome or ecosystem).

biological magnification The process in which synthetic chemicals concentrate as they move through the food chain, so that toxic effects are multiplied.

bionics Engineering which uses the design of biological organisms to develop efficient products.

desertification A process leading to production of a desert of formerly productive land.

extinction The cessation of existence of a species or group of taxa.

genetic pollution Hybridization or mixing of genes of a wild population with a domestic population.

habitat The ecological or environmental area where a particular species lives and the physical environment to which it has become adapted and in which it can survive.

habitat destruction The process in which a natural habitat is made functionally unable to support the species originally present.

invasive species Exotic species, introduced into habitats, which then eliminate or expel the native species.

slash-and-burn agriculture A method of agriculture in the tropics in which the forest vegetation is cut down and burned, then crops are grown for a few years, and then the forest is allowed to grow back.

tallgrass prairies Native prairie ecosystems with thick fertile soils, deep-rooted grasses, and other characteristic species.

wetlands A habitat that has a defined soil with characteristic vegetation and hydrology.

Points to Consider

- Global warming and climate change are frequently in the news these days, with reports of glaciers melting, and possible effects on species, such as the polar bear. Keep aware of these news trends and learn what you can about what species are becoming threatened.
- Our purchasing decisions may affect biodiversity: be more aware of the natural resources used to make and transport any product you buy; Buy recycled products whenever possible; when you buy fish for food, check to be sure that commercial species are not from overharvested areas.

Image Sources

(1) http://commons.wikimedia.org/wiki/Image:Obvious_water_pollution.jpeg. CC-BY 2.5.

(2) NOAA. http://upload.wikimedia.org/wikipedia/commons/f/f9/Atmosphere_layers-en.svg. NOAA.

(3) http://commons.wikimedia.org/wiki/File:Macquarie_perch.jpg. GNU-FDL.

(4) http://commons.wikimedia.org/wiki/File:Bioretention_cell_rain_garden_US_winter.jpg. Public Domain.

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Chapter 26

Appendix: Life Science

26.1 Investigation and Experimentation Activities

The following activities are based on information provided within this FlexBook or taken directly from the Teacher Edition.

The Scientific Method

Through this discussion, students will understand scientific tools and technology necessary to perform tests, collect data, analyze relationships, and display data, they will understand sources of unavoidable experimental error and reasons for inconsistent results, and how to formulate explanations by using logic and evidence.

The Five-legged Frog

Here is an example of a real observation made by students in Minnesota (**Figure** 26.1). Imagine that you are one of the students who discovered this strange frog. As you go through this discussion, determine the tools necessary to collect and analyze the data. Also take not of potential places for expeerimental errors. Lastly, develop a fictional set of data based on the experiments proposed in this discussion, analyze the data and present the data to the class.

Imagine that you are on a field trip to look at pond life. While collecting water samples, you notice a frog with five legs instead of four. As you start to look around, you discover that many of the frogs have extra limbs, extra eyes or no eyes. One frog even has limbs coming out of its mouth. You look at the water and the plants around the pond to see if there is anything else that is obviously unusual like a source of pollution.

Figure 26.1: A frog with an extra leg.?)

The next step is to ask a question about these frogs. For example, you may ask why so many frogs are deformed. You may wonder if there is something in their environment causing these defects. You could ask if deformities are caused by such materials as water pollution, pesticides, or something in the soil nearby.

Yet, you do not even know if this large number of deformities is "normal" for frogs. What if many of the frogs found in ponds and lakes all over the world have similar deformities? Before you look for causes, you need to find out if the number and kind of deformities is unusual. So besides finding out *why* the frogs are deformed, you should also ask:

"Is the percentage of deformed frogs in pond A (your pond) greater than the percentage of deformed frogs in other places?"

No matter what you observe, you need to find out what is already known about your topic. For example, is anyone else doing research on deformed frogs? If yes, what did they find out? Do you think that you should repeat their research to see if it can be duplicated? During your research, you might learn something that convinces you to alter your question.

Construct a Hypothesis

A hypothesis is a proposed explanation of an observation. For example, you might hypothesize that a certain pesticide is causing extra legs. If that's true, then you can *predict* that the water in a pond of healthy non deformed frogs will have lower levels of that pesticide. That's a prediction you can test by measuring pesticide levels in two sets of ponds, those with deformed frogs and those with nothing but healthy frogs. A hypothesis is an explanation that allows you to predict what results you will get in an experiment or survey.

The next step is to state the hypothesis formally. A hypothesis must be "testable."

Example:

After reading about what other scientists have learned about frog deformities, you predict what you will find in your research. You construct a hypothesis that will help you answer your first question.

"The percentage of deformed frogs in five ponds that are heavily polluted with a specific chemical X is higher than the percentage of deformed frogs in five ponds without chemical X."

Test Your Hypothesis

The next step is to count the healthy and deformed frogs and measure the amount of chemical X in all the ponds. This study will test the hypothesis. The hypothesis will be either true or false.

An example of a hypothesis that is not testable would be: "The frogs are deformed because someone cast a magic spell on them." You cannot make any predictions based on the deformity being caused by magic, so there is no way to test a magic hypothesis or to measure any results of magic. There is no way to prove that it is not magic, so that hypothesis is untestable and therefore not interesting to a scientist.

Analyze Data and Draw a Conclusion

If a hypothesis and experiment are well designed, the experiment will produce measurable results that you can collect and analyze. The analysis should tell you if the hypothesis is true or false.

Example:

Your results show that pesticide levels in the two sets of ponds are statistically different, but the number of deformed frogs is almost the same when you average all the ponds together. Your results demonstrate that your hypothesis is either false or the situation is more complicated than you thought. This gives you new information that will help you decide what to do next. Even if the results supported your hypothesis, you would probably ask a new question to try to better understand what is happening to the frogs and why. When you are satisfied that you have accurate information, you share your results with others.

Hypothesis vs. Theory

From this activity, students will understand the difference between a hypothesis and a scientific theory.

Develop a Research Plan

In chapter 1, the example of a plastic vs. wood cutting board is given. Ask students to develop a research plan involving other everyday items. First, students must develop a hypothesis, then formulate a plan to test their hypothesis. They may base their research plan around different brands of medicine (such as Tylenol vs. Advil) or different brands of food (such as soda), or other items they can think of.

Develop a list of student hypotheses on the board. Hypothetically, assume all the hypotheses proved true. Have the class develop a scientific theory based on these hypotheses. Discuss with the class the difference between the theory and the individual hypotheses, as well as the limitations of the theory.

Evaluation of Fossil Evidence

In this activity, students will analyze the time intervals associated with the succession of species in an ecosystem.

Have students critique the figure below, describing and evaluating the changes that occur at each evolutionary step depicted.

Accumulation of Scientific Evidence

In this activity students will understand the cumulative nature of scientific evidence.

Evolution is a Scientific Theory

Evolution by natural selection is supported by extensive scientific evidence. Have the class view the following video.

- PBS Evolution: Library: Isn't Evolution Just a Theory? http://www.pbs.org/wgbh/evolution/library/11/2/real/e_s_1.html 6 minute RealPlayer video

Follow with a class discussion. Point out that no evidence has been found on earth that is not explained by evolution. Discuss how much evidence has been discovered, why evolution is such a widely-held scientific theory, and what future discoveries may show.

Evolution as a theory does not simply mean a guess; it has been tested and supported by massive amounts of biological evidence from the fossil record and living species. Evolution can explain all evidence from the past two centuries of searching. In the future, we may find more about new species and their genomes from the fossil record, rainforests, and oceans.

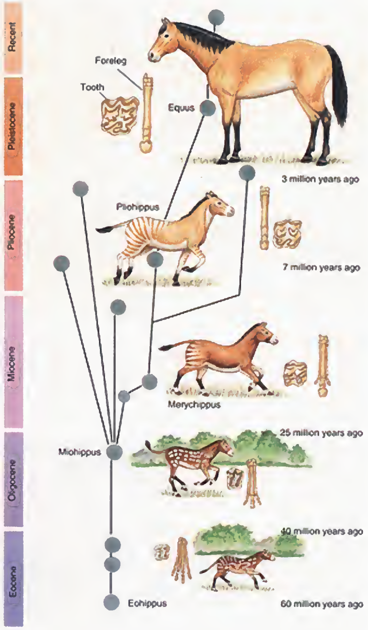


Figure 26.2: Evolution of the horse. Fossil evidence, depicted by the skeletal fragments, demonstrates evolutionary milestones in this process.?)

Is it the data or the theory?

Jean-Baptiste Lamarck proposed the idea that evolution occurs, but he did not suggest how it occurs. Darwin's theory of evolution by natural selection did discuss how evolution occurs. Though Darwin agreed with Lamarck that evolution occurs, he differed with Lamarck on several other points. Lamarck proposed that traits acquired during one's lifetime could be passed to the next generation. We now this is does not occur.

Discuss with the class how some data may not agree with an accepted scientific theory because sometimes the data is mistaken or fraudulent. Other times the theory may be wrong.

Science and Society

In this activity students will investigate a science-based societal issue by researching the literature, analyzing data, and communicating the findings. Students should incorporate concepts from biology and ecology into their responses.

Habitat Destruction

- Ask students if they understand that habitat destruction and biodiversity are related. How do they think these concepts might be intertwined? Begin discussion and accept all answers, writing some notes on the board.
- Have students research this topic, analyzing available date and presenting their findings to the class.

Students may choose to research the consequences of:

1. clearing habitats of vegetation for purposes of agriculture and development
2. habitats destruction by natural causes (lightning, earthquakes, fires, hurricanes, ice storms)
3. habitats destruction by humans
4. within the past 100 years, the significant increase in the area of cultivated land world-wide
5. the destruction of habitats on the species living in the habitats.

Science and Math

The Hardy-Weinberg Equation

Using a hypothetical rabbit population of 100 rabbits (200 alleles), determine allele frequencies for color:

- 9 albino rabbits (represented by the alleles bb) and
- 91 brown rabbits (49 homozygous [BB] and 42 heterozygous [Bb]).

The gene pool contains 140 B alleles [49 + 49 + 42] (70%) and 60 b alleles [9 + 9 + 42] (30%) – which have gene frequencies of 0.7 and 0.3, respectively.

Solution

If we assume that alleles sort independently and segregate randomly as sperm and eggs form, and that mating and fertilization are also random, the probability that an offspring will receive a particular allele from the gene pool is identical to the frequency of that allele in the population:

- BB: 0.7 x 0.7 = 0.49
- Bb: 0.7 x 0.3 = 0.21
- bB: 0.3 x 0.7 = 0.21
- bb: 0.3 x 0.3 = 0.09

If we calculate the frequency of genotypes among the offspring, they are identical to the genotype frequencies of the parents. There are 9% bb albino rabbits and 91% BB and Bb brown rabbits. Allele frequency remains constant as well. The population is stable – at a Hardy-Weinberg genetic equilibrium.

A useful equation generalizes the calculations we've just completed. Variables include

- $\boldsymbol{p}$ = the frequency of one allele (we'll use allele $\boldsymbol{B}$ here) and
- $\boldsymbol{q}$ = the frequency of the second allele ($\boldsymbol{b}$ in this example).

We will use only two alleles (so $\mathbf{p} + \mathbf{q}$ must equal 1), but similar equations can be written for more alleles.

Allele frequency equals the chance of any particular gamete receiving that allele. Therefore, when egg and sperm combine, the probability of any genotype is the product of the probabilities of the alleles in that genotype. So:

Probability of genotype $\boldsymbol{BB} = \boldsymbol{p}$ X $\boldsymbol{p} = \mathbf{p}^2$ and

Probability of genotype $\boldsymbol{Bb}$= ($\boldsymbol{p}$ X $\boldsymbol{q}$) + ($\boldsymbol{q}$ X $\boldsymbol{p}$) = $\mathbf{2pq}$ and

Probability of genotype $\boldsymbol{bb} = \boldsymbol{q}$ X $\boldsymbol{q} = \mathbf{q}^2$

We have included all possible genotypes, so the probabilities must add to 1.0. In our example 0.49 + 2(0.21) + 0.9 = 1. Our equation becomes:

Table 26.1:

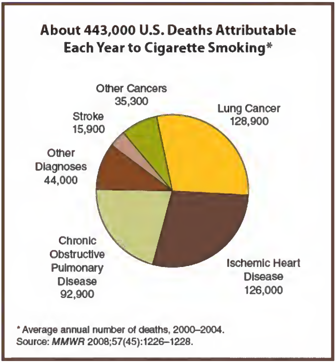
p^2	+	$2\ pq$	+	q^2	=	1
frequency of genotype BB		frequency of genotype Bb		frequency of genotype bb		

Science and Statistics

Carcinogens are a potential hazard, with one of the most recognizable carcinogens smoking. Have students analyze the graph and following comments and write a paragraph on what this information tells us. Students need to include all statistical data presented, and discuss the importance of these numbers.

As a class, discuss the importance of these numbers and the need for controlled experimentation when determining the consequences of cigarette smoke.

See the CDC (Centers for Disease Control and Prevention) web site (http://www.cdc.gov/NCCDPHP/publications/aag/osh.htm) for more information.



Tobacco use is the single most preventable cause of disease, disability, and death in the United States. For every person who dies from smoking, about 20 more people suffer from at least one serious tobacco-related illness.

The harmful effects of smoking do not end with the smoker. More than 126 million nonsmoking Americans, including children and adults, are regularly exposed to secondhand smoke. Even brief exposure can be dangerous because nonsmokers inhale many of the same carcinogens and toxins in cigarette smoke as smokers. Secondhand smoke exposure causes serious disease and death, including heart disease and lung cancer in nonsmoking adults and sudden infant death syndrome, acute respiratory infections, ear problems, and more frequent and severe asthma attacks in children.

Maps and Models

- Have students interpret the information shown on the map below.

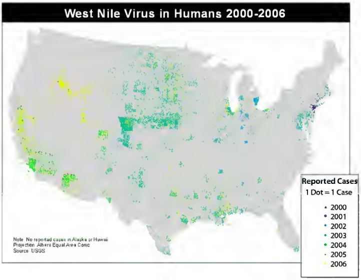


Figure 26.3: Epidemiologists study how diseases spread. The above map shows where humans contracted West Nile Virus between 2000 and 2006.?)

- Have students interpret the data in the model below and make a testable prediction based on the information presented in the model.

You use models for many purposes. A volcano model, is not the same as a volcano, but it is useful for thinking about real volcanoes. We use street maps to represent where streets are in relation to each other. A model of planets may show the relationship between the positions of planets in space. Biologists use many different kinds of models to simulate real events and processes. Models are often useful to explain observations and to make scientific predictions.

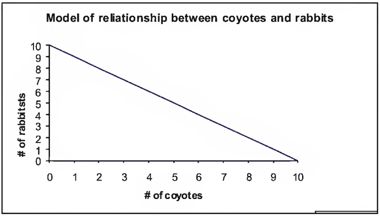


Figure 26.4: This graph shows a model of a relationship between a population of coyotes (the predators) and a population of rabbit, which the coyotes are known to eat (the prey).?
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